

VŠB-Technical University of Ostrava

Faculty of Civil Engineering

Department of Building Constructions

Reinforced Concrete Structure of Multifunctional Building

Železobetonová rámová konstrukce multifunkčního domu

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VŠB - Technical University of Ostrava
Faculty of Civil Engineering
Department of Building Structures

Diploma Thesis Assignment

Student: **Bc. Ali Subhi Naji Naji**
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Železobetonová rámová konstrukce multifunkčního domu
The thesis language: English

Description:

The aim of the diploma thesis is to design and assess reinforced concrete frame structure of multifunctional building. The plans are available as a study project elaborated at Faculty of civil engineering. Slab structures, horizontal and vertical load bearing elements, stairs and foundation slab will be designed within diploma thesis both for ultimate and for serviceability limit state. The structure will be analysed using FEM software. The static analysis will be complemented with drawings of reinforcement.

References:

EN 1991-1-1 (2002) Action on structures - Part 1-1: General actions - Densities, self weight, imposed load for buildings
EN 1991-1-3 (2003) Action on structures - Part 1-3: General actions - Snow loads
EN 1991-1-4 (2005) Action on structures - Part 1-3: General actions - Wind actions
EN 1992-1-1 (2004) Design of concrete structures - Part 1-1: General rules and rules for buildings

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

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Declaration of the student

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Annotation

The diploma thesis proposes a structural design of multifunctional building which is based on the plan as a study project at the faculty. The structural system was design as a monolithic skeleton. The load is collected by 2-ways monolithic slabs afterwards transferred into the beam, column and foundation.

The aim of the diploma thesis is to design and assess reinforced concrete structure of multifunctional building through my analyzing.

There was chosen the class concrete C30/37 and steel B500B. The main parts of the work are technical reports, all made calculations of the selected elements, general and detailed drawings.

Anotace

V této diplomové práci je designován strukturální návrh multifunkčního objektu, který vychází z plánu studijního projektu fakulty. Konstrukční system byl navržen jako monolitický skelet. Zatížení je dvoustrannými monolitickými deskami, které jsou poté přenášeny do nosníku, sloupu a základové desky.

Cílem diplomové práce je navrhnout a posoudit železobetonovou strukturu multifunkčního objektu prostřednictvím mé analýzy.

Byla vybrána třída betonu C30/37 a oceli B500B. Součástí práce jsou tehnické zprávy, provedené výpočty vybraných prvků, obecné a podrobné výkresy.

Keywords

Beam

Column

Slab

Foundation

Staircase

Wall

Klíčová slova

Nosník

Sloup

Deska

Základ

Schodiště

Stěna

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List of used symbols

| | |
|--------------|--|
| F | load |
| G | permanent load |
| M | moment |
| N | axial load |
| Q | variable load |
| T | torsional moment |
| V | shear force |
| B | width |
| d | effective depth of reinforcement |
| k | coefficient |
| l | length or span |
| s | spacing of shear reinforcement |
| t | thickness |
| u | punching shear perimeter |
| z | lever arm |
| c | cover depth |
| A_c | concrete cross sectional area |
| A_s | cross-sectional area of tension reinforcement |
| $A_{s,req}$ | cross-sectional area of tension reinforcement required at the ultimate limit state |
| $A_{s,prov}$ | cross-sectional area of tension reinforcement provided at the ultimate limit state |
| A_{sw} | cross-sectional area of shear reinforcement |
| G_k | characteristic permanent load |
| M_{bal} | moment on column corresponding to balanced condition |
| M_{Ed} | design value of moment |
| N_{bal} | axial load on column corresponding to balanced condition |
| N_{Ed} | design value of axial load |
| Q_k | characteristic variable load |
| V_{Ed} | design value of shear force |
| W_k | characteristic wind load |
| b_w | width of beam |

| | |
|---------------|--|
| f_{ck} | characteristic strength of concrete |
| f_{cm} | mean strength of concrete |
| f_{ctm} | mean tensile strength of concrete |
| f_{yk} | characteristic yield strength of reinforcement |
| γ_c | partial safety factor for concrete strength |
| γ_s | partial safety factor for steel strength |
| γ_Q | partial safety factor for variable loads |
| γ_G | partial safety factor for permanent loads |
| ε | strain |
| σ | stress |
| \varnothing | bar diameter |
| b_{eff} | effective width of concrete flange |

1. Technical report

1.1 Basic description

The project is a manufactural building, which could be used as a shop, storage or office center as there is the advantage of parking. The building is consisting of 5 floors plus parking and basement in the ground floor. The roof of the building is flat covered by bitumen on the top.

There were made some changes in the project, especially in the shape. Actually, the building has rectangle shape with the dimensions 23,5m x 19,8m, so the built-up area is 465,3 m².

The building is consisted of five columns with the distance between each other is 6 meters.

The maximum span of slab is 8m x 6m.

There were designed staircase and elevator to serve the vertical communications.

1.2 Materials

Reinforcement B500B

Concrete C30/37 characteristics:

Compression Strength of concrete $f_{ck} = 30$ MPa

Tensile Strength $f_{ctk, 0.05} = 2$ MPa

Mean Tensile Strength $f_{ctm} = 2.9$ MPa

Ultimate strain $\epsilon_{cu1} = 0.0035$

Reinforcement steel bars B500B characteristics

Characteristic yield strength $f_{yk} = 500$ MPa

1.3 Partial factors

$\gamma_c = 1.5$ for concrete in ultimate limit state

$f_{cd} = f_{ck} / \gamma_c = 30 / 1.5$, $f_{cd} = 20$ MPa. (Design value of concrete compressive strength).

The strength properties of the reinforcement are expressed in terms of the characteristic yield.

Strength, f_{yk} .

$\gamma_s = 1.15$ (partial factor for steel strength)

$f_{yd} = f_{yk} / 1.15$, $f_{yd} = 500 / 1.15 = 435$ MPa (Design yield strength of reinforcement).

1.4 Loads

The loads on building are divided in two types: permanent loads and variable load. Permanent loads for slab include self-weight, partition load and dead load. Variable load for slab includes live load.

Permanent loads for roof include self-weight and dead load. Variable loads for roof include snow load and wind load.

1.5 Structure system

The structural system is monolithic skeleton system for both floors - ground floor and for regular floors. The building includes slab, beam, column, staircase, wall.

Slab

The slab 200 mm thick is supported on all four of its sides so it effectively spans in both directions. Sometimes it is more economical to design the slab on this basis. The slab is rectangular therefore more of the loads will carry in shorter direction and less in longer direction. Moments in each directions of span are generally calculated using table coefficient. The area of the reinforcement resists the moments which are determined independently for each direction of span.

Beam

The beam with the height 300 mm and the width 300 mm reinforcement concrete of beam is designed in typical floor consists primarily of producing member details which will adequately resist ultimate bending moments and shear forces.

Column

The column in a floor carries the loads from the beams and slabs down to the foundations. The design of the columns is governed by the ultimate limit state, deflection and cracking during service condition are not usually problems, but probably correct detailing of the reinforcement and enough cover are important. The dimensions of the columns are 400mm×400mm, but from the third floor the column dimensions decrease into the with 350x350mm.

Staircase

There is designed staircase to serve the vertical communications from the ground floor up to the roof. The design of the staircase is the two-flight staircase type carrying in two directions and supported by load bearing wall. The dimension of each stair is following: Height 170mm; Depth 290 mm.

The staircases are made of concrete.

Wall

The external wall is made of concrete, split into 3 stages – stability analysis, bearing pressure analysis, member design. There is used the thermal insulation EPS Grey Wall Plus. The thickness of the walls is from 250mm to 200mm.

1.6 Foundation

The building is generally composed of a superstructure above the ground and a substructure which form the foundation below ground. The foundation transfers and spreads the loads from structure's column and wall into the ground. Geotechnical design and classification of subsoil is according with EN-1997: Eurocode 7. For the reinforced concrete the value of load bearing angle is 30°-45°. The thickness of the slab foundation is 400mm.

1.7 Insulation

Thermal insulation EPS Grey Wall Plus with thickness 250 mm is used for external wall and roof structure. XPS insulation is used with thickness 150mm and 100mm at the bottom part of the building.

Inside the of the basement is mineral wool insulation (thickness 150mm) applied on ceiling to separate heated and unheated space.

To protect the building against moisture is used the hydrophobic silicon plaster at the ground level.

Bitumen waterproofing is present in basement slab and roof slab. In both locations, two layers are used. To insulate foundations, epoxy paint is used.

Acoustic insulation layer is used on the slab (thickness 50mm) and around the slab (thickness 20mm) to prevent transmission of impact noise.

2. Structural analysis

2.1 Dimensions of elements

Depth of slab h_s

For two-way slab

Cover depth (C)

Empirical estimation $h_s = \frac{1}{75}(l_x + l_y)$ where l_x, l_y are the dimension of largest slab:

$$h_s = \frac{1}{75}(8 + 6) = 0.187\text{m}$$

$$h_s = 187\text{mm}.$$

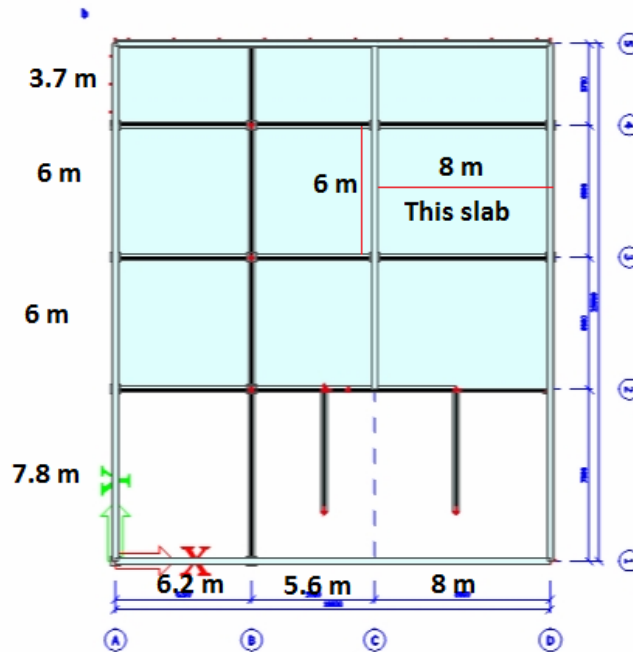


Figure 1-Plan of the building

Cover depth (C)

$$C = C_{\min} + \Delta C_{\text{dev}}.$$

$$C_{\min} = \max(C_{\min,b}, C_{\min,\text{dur}}, 10\text{mm}).$$

$\Delta C_{\text{dev}} = 10\text{mm}$ technology allowance.

$C_{\min,b} = 10\text{mm}$ cover depth necessary for good mechanical bond between steel and concrete.

ΔC_{dev} = according to the exposure class related to environmental conditions EN-1992-1-1:2004 (x_{c2}).

$C_{\min,\text{dur}} = 15\text{mm}$ (the max of 3 values). See the table (cover depth necessary for good

resistance to unfavorable effects of the environment).

$C_{\min} = 15\text{mm}$; $C = 15 + 10 = 25\text{mm}$ the cover of depth $C = 25\text{mm}$

| Values of $c_{\min, \text{dur}}$ [mm] | | | | | | | |
|---------------------------------------|--|-----|---------|-----|---------|---------|---------|
| Structural class | Exposure class related to environmental conditions | | | | | | |
| | X0 | XC1 | XC2/XC3 | XC4 | XD1/XS1 | XD2/XS2 | XD3/XS3 |
| S1 | 10 | 10 | 10 | 15 | 20 | 25 | 30 |
| S2 | 10 | 10 | 15 | 20 | 25 | 30 | 35 |
| S3 | 10 | 10 | 20 | 25 | 30 | 35 | 40 |
| S4 (for 50 years) | 10 | 15 | 25 | 30 | 35 | 40 | 45 |
| S5 | 15 | 20 | 30 | 35 | 40 | 45 | 50 |
| S6 | 20 | 25 | 35 | 40 | 45 | 50 | 55 |

| Structural class | | | | | | | | |
|-------------------------------------|--|--------|--------|--------|--------|---------|---------|---------|
| Criterion | Exposure class related to environmental conditions | | | | | | | |
| | X0 | XC1 | XC2 | XC3 | XC4 | XD1/XS1 | XD2/XS2 | XD3/XS3 |
| Working life 80 years | increase class by 1 | | | | | | | |
| Working life 100 years | increase class by 2 | | | | | | | |
| Concrete class | decrease class by 1 if concrete class is at least: | | | | | | | |
| | C20/25 | C25/30 | C30/37 | C35/45 | C40/50 | C40/50 | C40/50 | C45/55 |
| Member with slab geometry | decrease class by 1 | | | | | | | |
| Special quality control of concrete | decrease class by 1 | | | | | | | |

Figure 2 -Table of exposure classes related to environmental conditions¹

Effective Depth (d)

$$d = h_s - c - \frac{\emptyset}{2} = 187 - 25 - \frac{12}{2} = 156\text{mm} \text{ the effective depth.}$$

Span/depth ratio (bending slenderness)

$$\lambda = \frac{l}{d} < \lambda_{\text{lim}} \rightarrow \lambda_{\text{lim}} = k_{c1} k_{c2} k_{c3} \lambda_{d, \text{tab}}, \text{ Where } l \text{ is the minimum span of the slab,}$$

$k_{c1} = 1$ (effective of shape), $k_{c2} = 1$ (effective of span), $k_{c3} = 1.2$ (effective of reinforcement),

$\lambda_{d, \text{tab}} = 30.8$ according to the concrete class (see table)

$\lambda_{d, \text{tab}}$ for inner span of the continuous beam/slab

| | Concrete class | | | | | | |
|--------|----------------|-------|-------|-------|-------|-------|-------|
| ρ | 12/15 | 16/20 | 20/25 | 25/30 | 30/37 | 40/50 | 50/60 |
| 0,5 % | 21,9 | 23,7 | 25,5 | 27,8 | 30,8 | 38,6 | 48 |
| 1,5 % | 18,3 | 18,9 | 19,5 | 20,3 | 21 | 22,5 | 24 |

Figure 3 -Table of inner span of the continuous beam/slab²

¹ EN 1992-1-1, December 2004. s 51

² Bílý, P. *Seminar of the Concrete structures*, Praha: Ceske Vysoke Ucení Technické, 2014. s 10

$$\lambda = \frac{5600}{156} \rightarrow \lambda = 25.89$$

$$\lambda \leq \lambda_{lim} \quad 25.85 \leq 36.96$$

Structures designed to meet this condition are safe.

suggest $h_s=200$ mm, $d_s=156$ mm.

Dimensions of beam

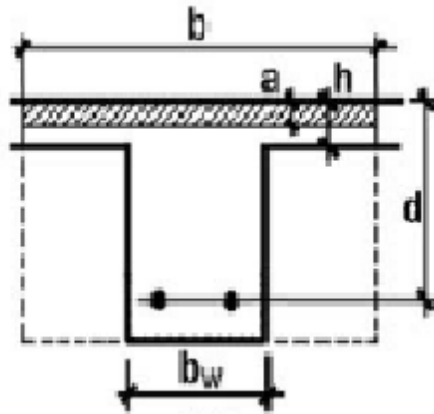


Figure 4 -Shape of beam

Height of beam (h_B) $\rightarrow h_B = \dots$ where l span is largest

Span of slab

$$h_B = \left(\frac{1}{12} \sim \frac{1}{15} \right) 8000 \times \text{mm} = 667 \text{mm} \sim 534 \text{mm}$$

$$h_b = 570 \text{mm}.$$

Check stiffness of beam, if it is sufficient or not!

$$h_B \geq 2.5 h_s \rightarrow 500 \geq 2.5 \times 200 \text{mm} \rightarrow 500 \text{mm} \geq 500 \text{mm}!$$

The condition is fulfilled

$$h_B = 500 \text{mm}$$

$$\text{Width of beam } (b_w) \rightarrow \text{estimation } b_w = \left(\frac{1}{3} \sim \frac{1}{2} \right) h_B, b_w = \left(\frac{1}{3} \sim \frac{1}{2} \right) \times 500 \text{mm}$$

$$b_w = 166.7 \sim 250$$

$$b_w = 300 \text{mm}$$

for all building the dimensions of beams:

$$B_w = 300 \text{ mm}, h_B = 300 \text{ mm}$$

2.2 Loads

Slab load

Permanent load (kN.m^{-2})

| Slab load | Characteristic(kN.m^{-2}) | γ_G | Design value(kN.m^{-2}) |
|----------------|---------------------------------------|------------|------------------------------------|
| Self-weight | $0.2 \times 25 = 5 \text{ kN.m}^{-2}$ | 1.35 | 6.75 – LC1 |
| Partition load | 1 | 1.35 | 1.35 |
| Dead load | 1.75 | 1.35 | 2.363 |

Figure 5 -Table of permanent load of slab

Variable load kN.m^{-2}

| Slab load | Characteristic(kN.m^2) | γ_Q | Design value(kN.m^{-2}) |
|-----------|-----------------------------------|------------|------------------------------------|
| Live load | 3 | 1.5 | 4.5 |

Figure 6 -Table of variable load of slab

Roof load

Permanent load kN/m^2

| Roof load | Characteristic(kN.m^2) | γ_G | Design value(kN.m^{-2}) |
|-------------|---------------------------------------|------------|------------------------------------|
| Self-weight | $0.2 \times 25 = 5 \text{ kN.m}^{-2}$ | 1.35 | 6.75 |
| Dead load | 1.56 | 1.35 | 2.11 |

Figure 7 -Table of permanent load of roof

The total permanent roof load is 8.86 kN/m^2 .

Remark

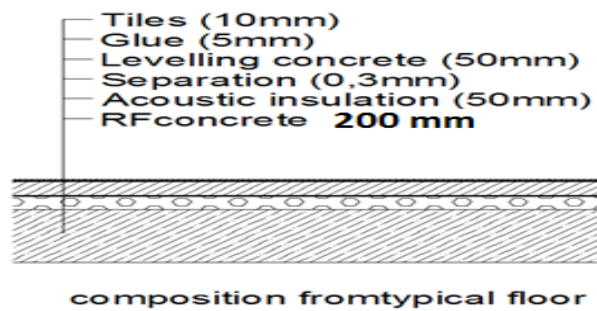


Figure 8 -Composition of slab

The data design from typical floor:

Tiles= 0.32 kN/m^2

Glue= 0.05 kN/m^2

Acoustic insulation= 0.026 kN/m^2

Leveling concrete= 1.2 kN/m^2

The total data design dead load from typical floor = 1.75 kN/m^2

The total permanent load = 10.46 kN/m^2 .

For SCIA program total permanent load = $2,75 \text{ kN/m}^2$

Remark

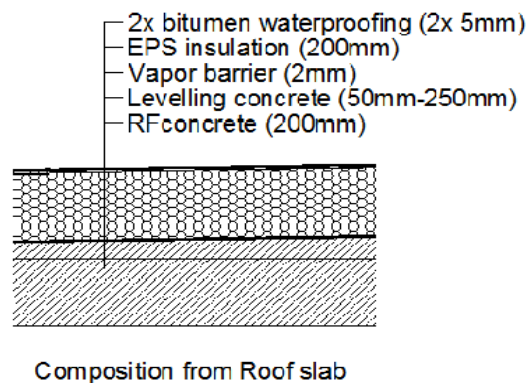


Figure 9 -Composition of roof

The data design from roof slab:

2x bitumen= 0.11 kN/m^2

EPS insulation; (Polystyrene)= 0.1 kN/m^2

Leveling concrete= 1.2 kN/m^2 ; Services= 0.15 kN/m^2

Total data design dead load from roof slab = 1.56 kN/m^2 .

Wind load

$$q_b = \frac{1}{2} \times 1.25 \times 25^2 \quad q_b = 0.392 \text{ kN.m}^{-2}$$

Height of building = 14,5m

IV – category of city

From diagram $c_e(z) = 1.5$

| part | A | | B | | C | | D | | E | |
|----------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|---------------|
| h/d | $c_{pe,10}$ | $c_{pe,1}$ | $c_{pe,10}$ | $c_{pe,1}$ | $c_{pe,10}$ | $c_{pe,1}$ | $c_{pe,10}$ | $c_{pe,1}$ | $c_{pe,10}$ | $c_{p_{e,1}}$ |
| 5 | -1,2 | - | -0,8 | - | -0,5 | | 0,8 | 1,0 | -0,7 | |
| 1 | | | | | | | | | -0,5 | |
| \leq 0,25 | | | | | | | 0,7 | | -0,3 | |

Figure 10 -Table of external pressure

The design value of wind load $\rightarrow w_k = q_b \times c_e(z) \times c_{pe}$:

$$w_k = 0.391 \times 1.5 \times 0.8 = 0.5 \text{ kN/m}^2$$

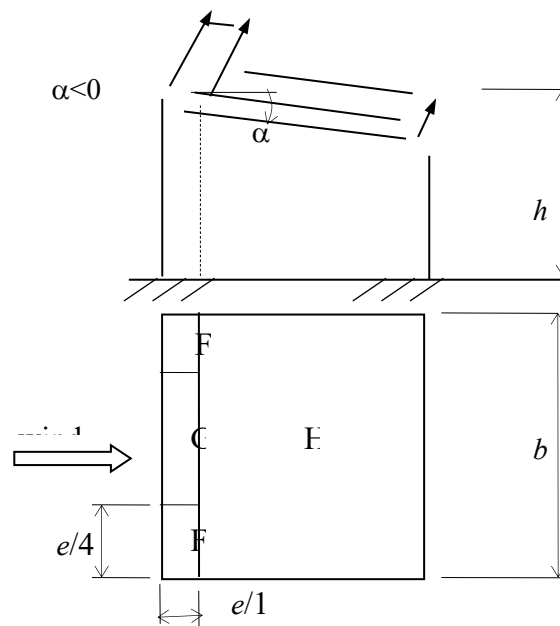


Figure 11 -Distribution areas of wind pressure on the roof

$$w_k = 0.391 \times 1.5 \times -0.5 = -0.3 \text{ kN/m}^2$$

Perpendicular wall

$$w_k = 0.391 \times 1.5 \times -1.2 = -0.7 \text{ kN/m}^2$$

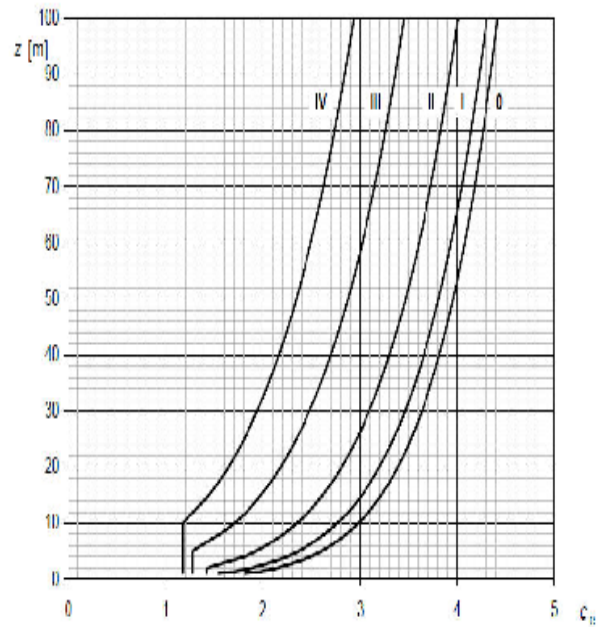


Figure 12 -Table of exposure factor, based on the type of terrain and height of building³

Snow Load



Figure 13 -Map of the snow load in CR⁴

³ Bílý, P. *Střešeburg walls*, Praha: Ceske Vysoke Ucení Technicke, 2017. s 9

⁴ EN 1991-1-3, 2005

Snow category II – Prague

Characteristic value of snow load

$s_k = 1.0 \text{ kN/m}^2$

Factor according to exposure normal: $C_e = 1,0 \quad C_t = 1,0$

Coefficients of snow load - for the roof $\alpha = 2^\circ \quad \mu_1 = 0,8$

Snow load value: $s = \mu_i \cdot C_e \cdot C_t \cdot s_k = 0,8 \cdot 1,0 \cdot 1,0 \cdot 1,0 = 0,8 \text{ kN/m}^2$

Snow load = $0,8 \text{ kN/m}^2$

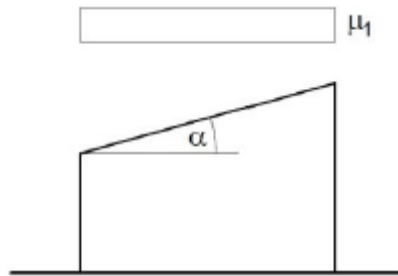


Figure 14 -Distribution areas of wind pressure on the roof

Variable load kN/m^{-2}

| Roof load | Characteristic(kN.m^{-2}) | γ_Q | Design value(kN.m^{-2}) |
|-----------|--------------------------------------|------------|------------------------------------|
| Snow load | 0.8 | 1.5 | 1.125 |
| Wind load | | | 0,3 |

Figure 15 -Table of variable load of roof

2.3 Static analysis of the building

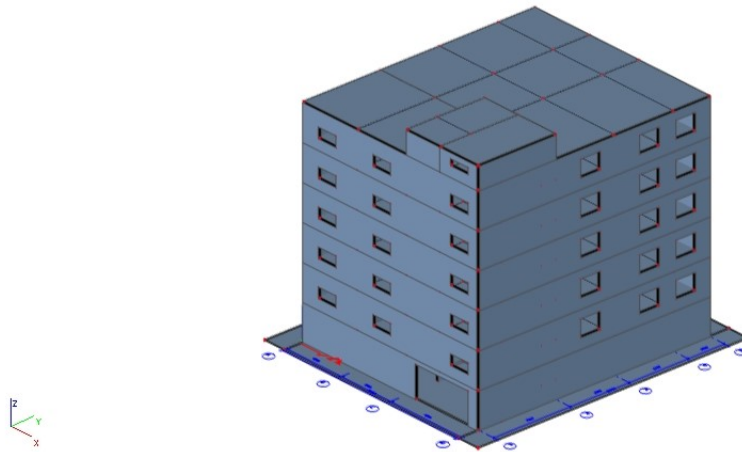


Figure 16 -3D model of the Multifunctional building

Loads applied on model

The self-weight load calculated by software

Partition load + floor loading + roof loading +stair case load

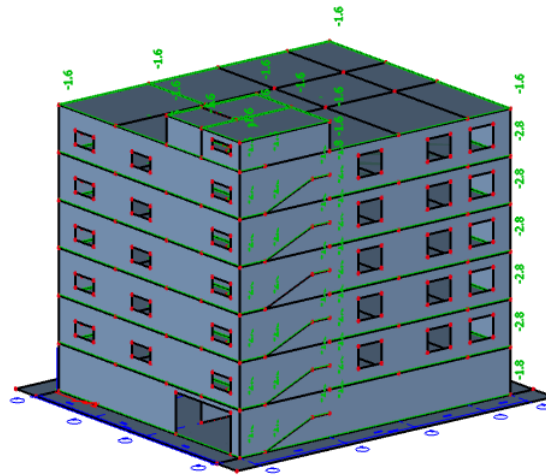


Figure 17 -3D model of the multifunctional building with loads

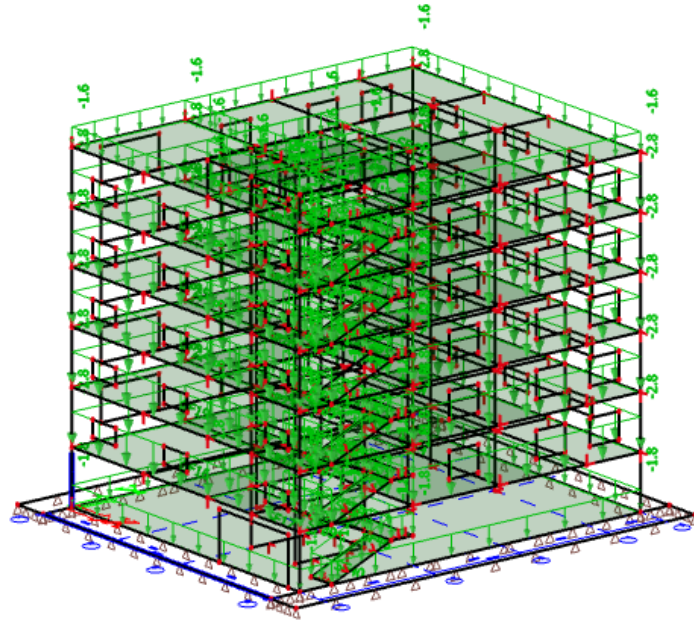


Figure 18 -3D permanent load model

Variable load

Live load + Roof load even

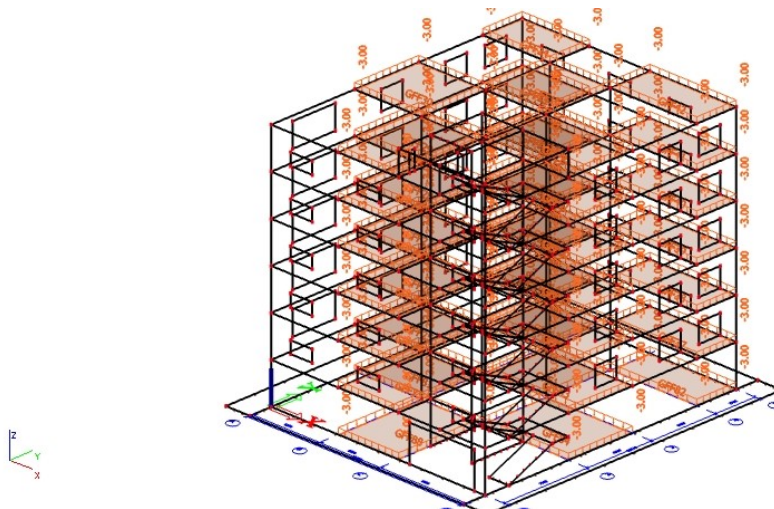


Figure 19 -3D variable load model

Live load+ Roof load odd

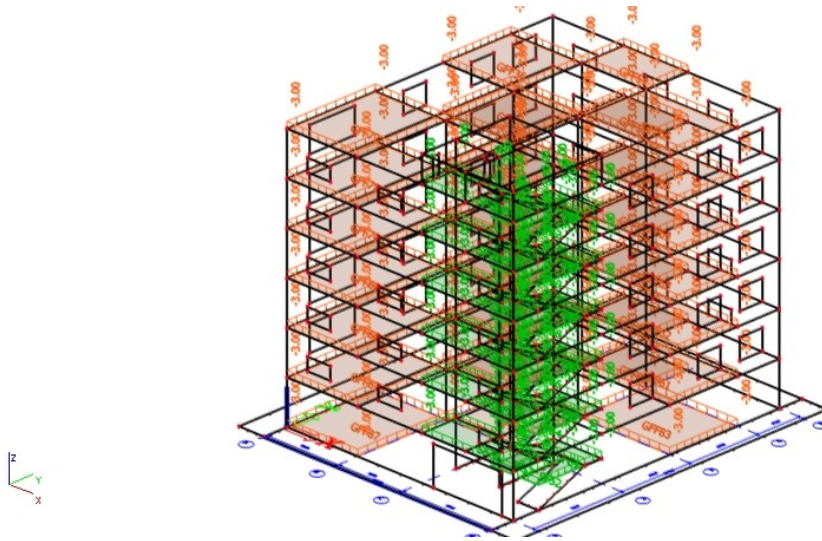


Figure 20 -Live and roof load

Wind load

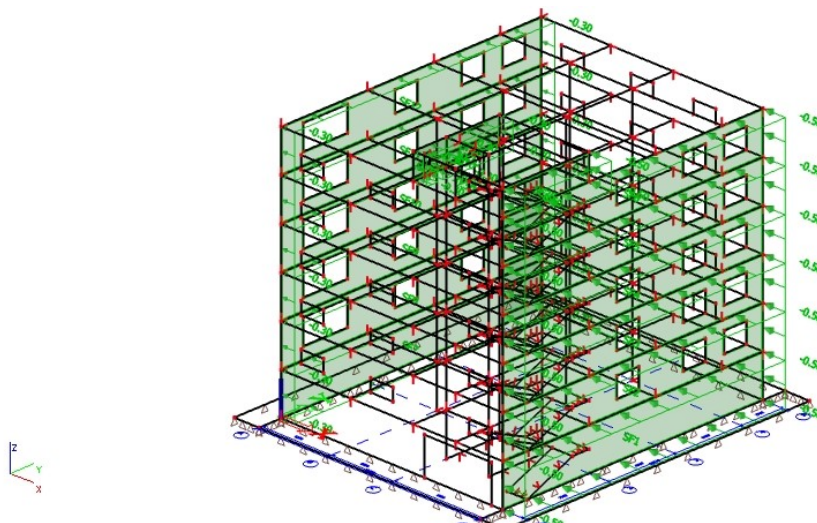


Figure 21 - 3D wind load model

Snow load

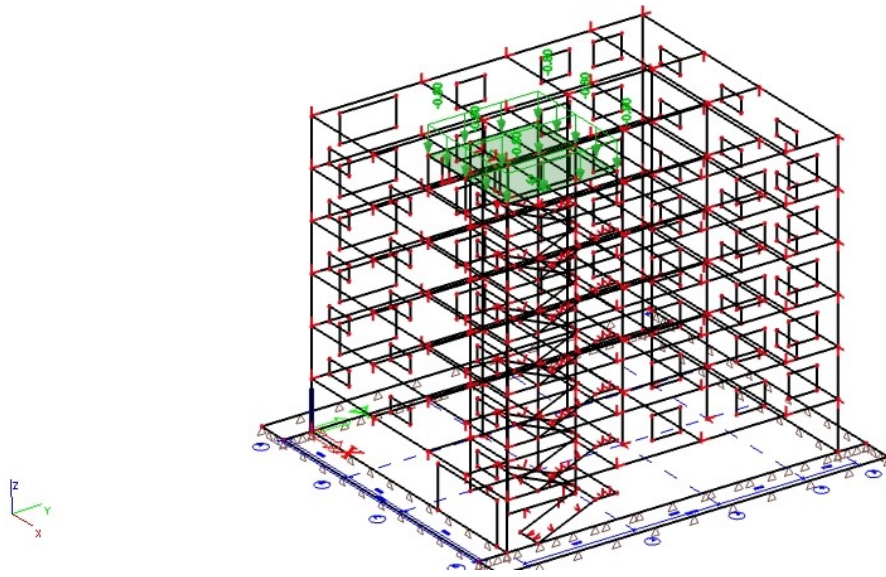


Figure 22 -3D snow load model

3. Foundation design

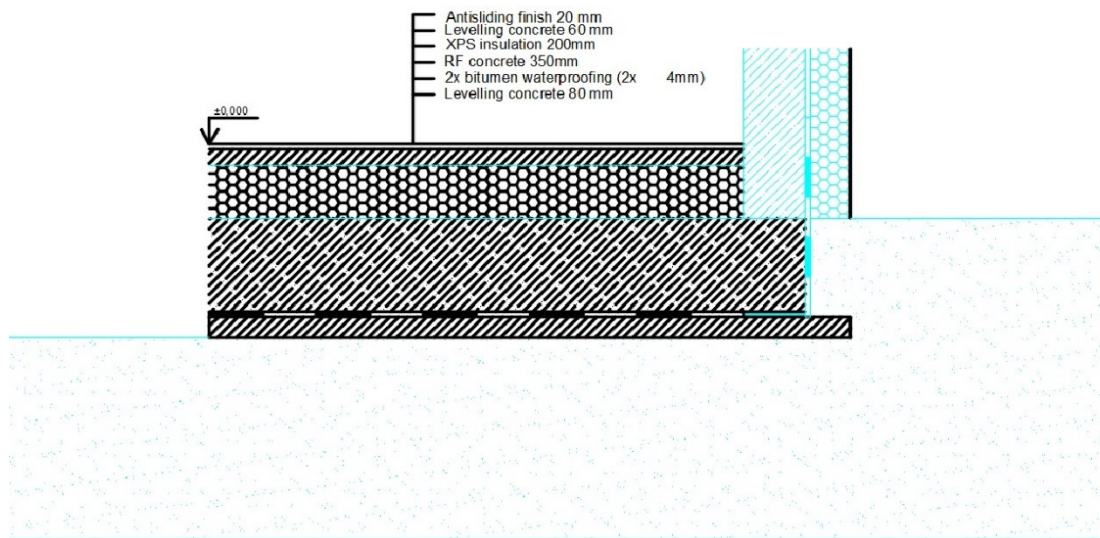


Figure 23 -Composition of foundation

The results of site investigation report use below borehole log.

Brief description of the borehole log:

| | |
|----------------|--|
| 0,00 - 0,30m | Top soil |
| 0,30 - 1.60m | Fine silty sand, medium dense $E_{oed} = 18 \text{ MPa}$ |
| 1,60 - 3,50 m | Fine sandy silt, firm (silt with - low plasticity) $E_{oed} = 12 \text{ MPa}$ |
| 3,50 - 8,20m | Fine gravelly coarse sand, dense $\phi' = 20^\circ$, $c' = 30 \text{ kPa}$, $\gamma = 20,0 \text{ kN/m}^3$, $E_{oed} = 20 \text{ MPa}$ |
| 8,20 - 12,70 m | River deposits - sand to sandy gravel poorly graded, $E_{oed} = 40 \text{ MPa}$ |
| 12,70 – 14,50m | Weathered shale $E_{oed} = 35 \text{ MPa}$ |
| 14,50 – ... | Slightly weathered shale Rock base |

Ground water level: 1,80 m indicated by boring

For the reinforcement concrete the value of load bearing angle is $(30^\circ - 45^\circ)$.

3.1 Stress on the foundation

$$\sigma_d = 201.2 \text{ kPa}$$

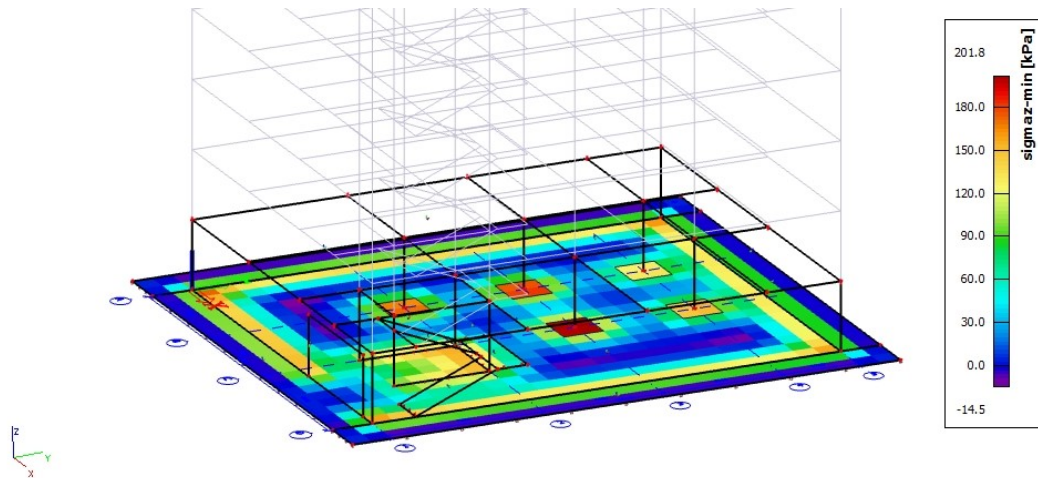


Figure 24 -Stress on the foundation

3.2 Bearing estimation of the subsoil

Bearing Capacity Based on Presumptive Analysis

| Types | Safe /allowable bearing capacity(kN/ m ²) |
|-----------------------|---|
| Rocks | 3240 |
| Soft rocks | 440 |
| Coarse sand | 440 |
| Medium sand | 245 |
| Fine sand | 100 |
| Soft shale/stiff clay | 440 |
| Soft clay | 100 |
| Very soft clay | 50 |

Figure 25 -Table of bearing capacity⁵

$R_d = 705.455 \text{ kPa}$ the design strength of subsoil.

$\sigma_d = 201.2 \text{ kPa} \leq R_d = 245 \text{ kPa}$ ok the design is safe and economic.

⁵ <https://www.slideshare.net/HarigovindSreekumar/bearing-capacity-of-soil-final>, 27.11.2018

3.3 Bending moment

Bending moment on the support direction x

$$M_{Ed,slab,F} = 320 \text{ kN.m.}$$

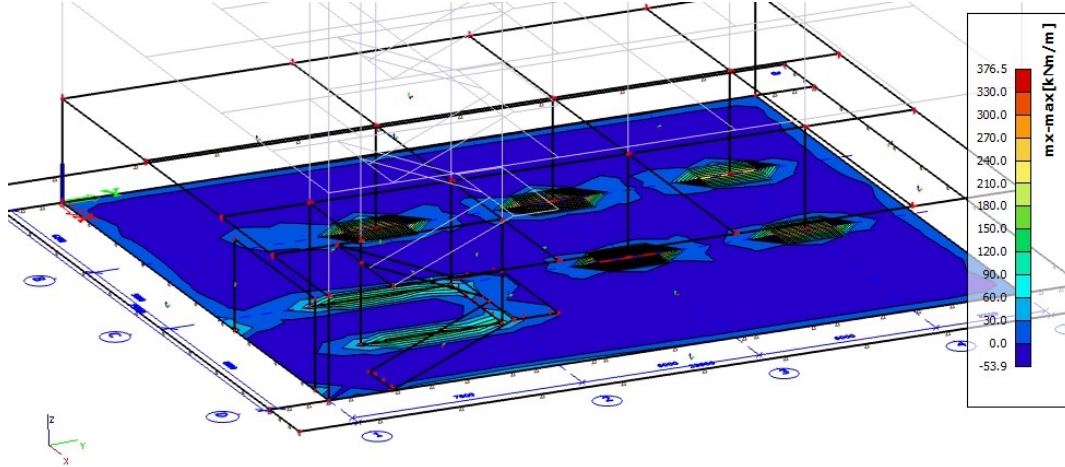


Figure 26 -Bending moment on the support direction x

The design of reinforcement of foundation

$$d = h_s - c - \frac{\emptyset}{2} = 350 - 50 - \frac{12}{2} = 294 \text{ mm the effective depth.}$$

$$z = 0.9d, z = 0.9 \times 169 = 264 \text{ mm}$$

$$\text{The required reinforcement: } A_{S, \text{support}} = \frac{M_{Ed, \text{support1}}}{z \cdot f_{yd}} = \frac{320}{264 \cdot 435} = 2786 \text{ mm}^2$$

$$A_{S, \text{support}} = 2786 \text{ mm}^2$$

$$9 \text{ bars with } 20 \text{ } \emptyset \text{ diameter, } A_{S, \text{Prov, support}} = 9 \times \pi \times 10^2 = 2830 \text{ mm}^2$$

$$\text{Position of neutral axis: } x = \frac{A_{S, \text{Prov, support, 1}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{2830 \times 435}{0.8 \times 1000 \times 20} = 76.9 \text{ mm}$$

$$\xi = \frac{76.9}{294} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.26 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{support}} = d - 0.4 \cdot x_{\text{support}} = 294 - 30.7 = 263 \text{ mm.}$$

$$\begin{aligned} \text{Bending moment of slab at support} &= M_{Rd, \text{support}} = A_{S, \text{Req, support}} \times f_{yd} \times z_{\text{support}} \\ &= 2830 \times 435 \times 263 \times 10^{-6} = 39.3 \text{ kN.m.} \end{aligned}$$

$$M_{Rd, \text{support}} = 373 \text{ kN.m} \geq M_{Ed, \text{support}} = 320 \text{ kN.m.} \text{..Ok}$$

Bending moment from mid-span direction x

$$M_{Ed, m} = 220 \text{ kN.m.}$$

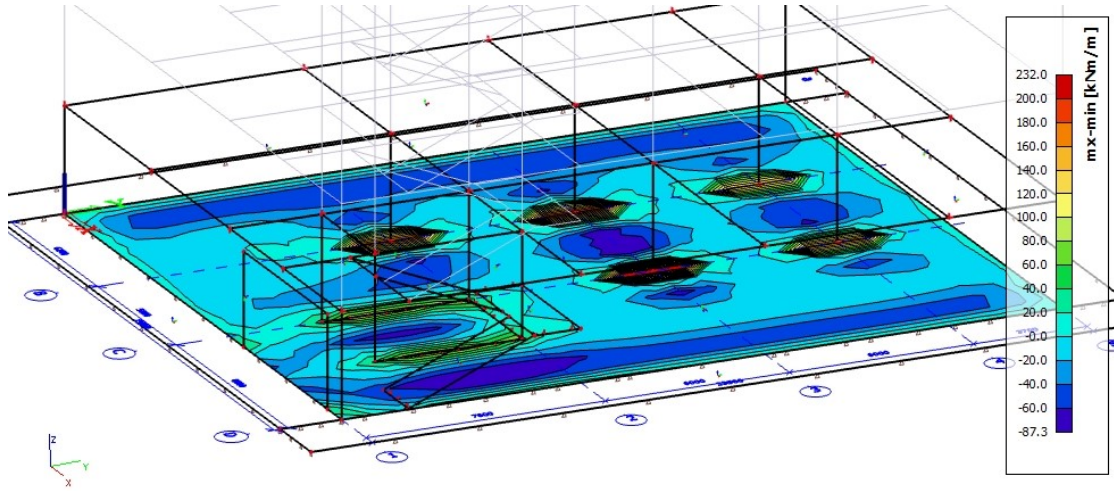


Figure 27 -Bending moment from mid-span direction x

The design of reinforcement of foundation

$$d = h_s - c - \frac{\emptyset}{2} = 350 - 50 - \frac{12}{2} = \mathbf{294 \text{ mm}}$$
 the effective depth.

$$z = 0.9d, z = 0.9 \times 294 = 264 \text{ mm}$$

$$\text{The required reinforcement: } A_{S, \text{mid-span}} = \frac{M_{Ed, \text{mid-span}}}{z \cdot f_{yd}} = \frac{220}{264 \times 435} = 1915 \text{ mm}^2$$

$$A_{S, \text{mid-span}} = \mathbf{1915 \text{ mm}^2}$$

$$\mathbf{7 \text{ bars with } 20 \text{ } \emptyset \text{ diameter, } A_{S, \text{Prov, mid-span}} = 7 \times \pi \times 10^2 = 2200 \text{ mm}^2}$$

$$\text{Position of neutral axis: } x = \frac{A_{S, \text{Prov, mid-span}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{2200 \times 435}{0.8 \times 1000 \times 20} = \mathbf{59.8 \text{ mm}}$$

$$\xi = \frac{59.8}{294} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.2 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{mid-span}} = d - 0.4 \cdot x_m = 294 - 23.9 = \mathbf{270 \text{ mm.}}$$

$$\text{Bending moment of slab at mid-span} = M_{Rd, \text{mid-span}} = A_{S, \text{Req, mid-span}} \times f_{yd} \times z_{\text{mid-span}} =$$

$$2200 \times 435 \times 270 \times 10^{-6} = 32.9 \text{ kN.m.}$$

$$\mathbf{M_{Rd, mid-span} = 287 \text{ kN.m} \geq M_{Ed, mid-span} = 220 \text{ kN.m..Ok}}$$

The bending on the support moment direction y

$$M_{Ed,S} = 320 \text{ kN.m}$$

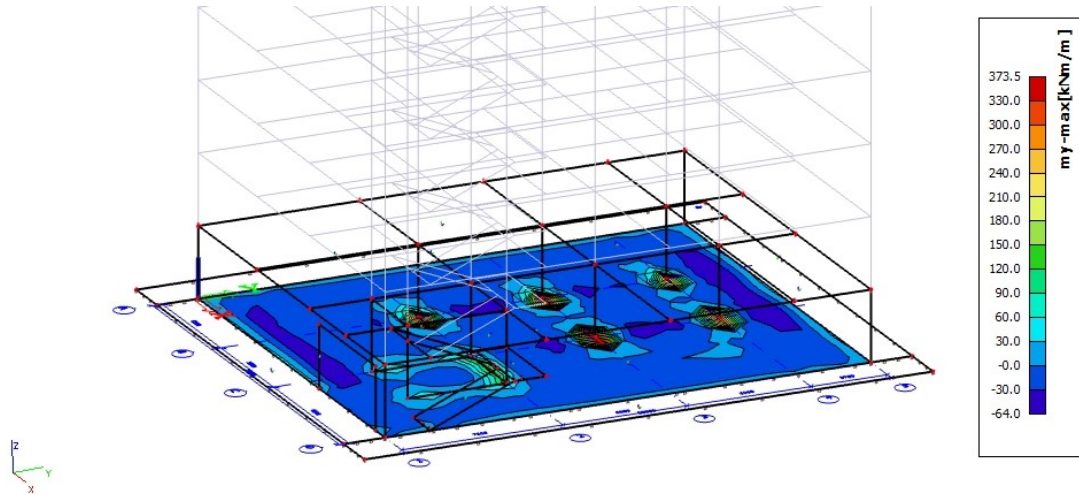


Figure 28 -Bending moment on the support direction y

The design of reinforcement of foundation

$$d = h_s - c - \frac{\phi}{2} = 350 - 50 - \frac{12}{2} = 294 \text{ mm the effective depth.}$$

$$z = 0.9d, z = 0.9 \times 294 = 264 \text{ mm}$$

$$\text{The required reinforcement: } A_{S,\text{support}} = \frac{M_{Ed,\text{support1}}}{z \cdot f_{yd}} = \frac{320}{264 \cdot 435} = 2786 \text{ mm}^2$$

$$A_{S,\text{support}} = 2786 \text{ mm}^2$$

$$\text{9 bars with 20 } \phi \text{ diameter, } A_{S,\text{Prov},\text{support}} = 9 \times \pi \times 10^2 = 2830 \text{ mm}^2$$

$$\text{Position of neutral axis: } x = \frac{A_{S,\text{Prov},\text{support}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{2830 \times 435}{0.8 \times 1000 \times 20} = 76.9 \text{ mm}$$

$$\xi = \frac{76.9}{294} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.26 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{support}} = d - 0.4 \cdot x_{\text{support}} = 294 - 30.7 = 263 \text{ mm.}$$

$$\begin{aligned} \text{Bending moment of slab at support} &= M_{Rd,\text{support}} = A_{S,\text{Req},\text{support}} \times f_{yd} \times z_{\text{support}}, \\ &= 2830 \times 435 \times 263 \times 10^{-6} = 39.3 \text{ kN.m.} \end{aligned}$$

$$M_{Rd,\text{support}} = 373 \text{ kN.m} \geq M_{Ed,\text{support}} = 320 \text{ kN.m. Ok}$$

The maximum bending moment from mid-span direction y

$$M_{Ed,m} = 75 \text{ kN.m.}$$

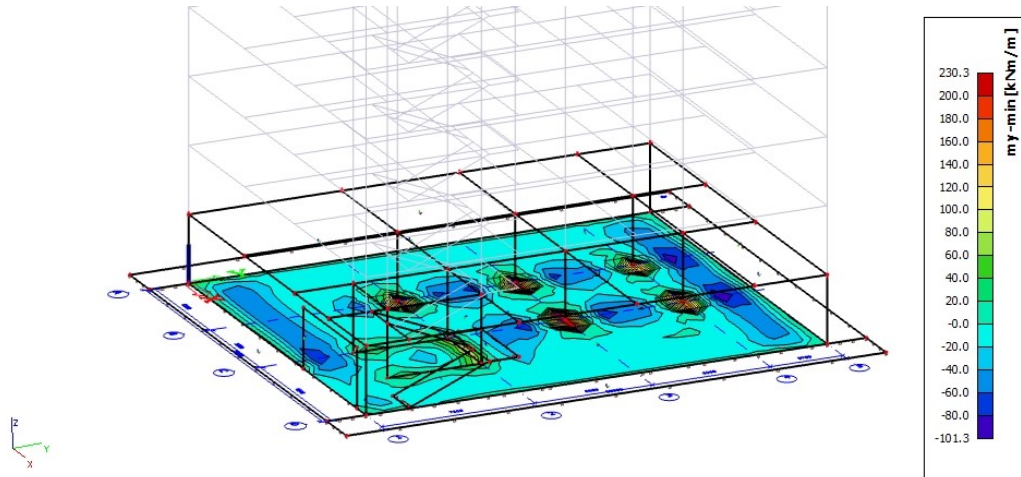


Figure 29 -Bending moment from mid-span direction y

The design of reinforcement of foundation

$$d = h_s - c - \frac{\phi}{2} = 350 - 50 - \frac{12}{2} = \mathbf{294 \text{ mm}}$$
 the effective depth.

$$z = 0.9d, z = 0.9 \times 294 = 264 \text{ mm}$$

$$\text{The required reinforcement: } A_{S,\text{mid-span}} = \frac{M_{Ed,\text{mid-span}}}{z \cdot f_{yd}} = \frac{220}{264 \times 435} = 1915 \text{ mm}^2$$

$$A_{S,\text{mid-span}} = \mathbf{1915 \text{ mm}^2}$$

$$\mathbf{7 \text{ bars with } 20 \text{ } \phi \text{ diameter, } A_{S,\text{Prov},\text{mid-span}} = 7 \times \pi \times 10^2 = 2200 \text{ mm}^2}$$

$$\text{Position of neutral axis: } x = \frac{A_{S,\text{Prov},\text{mid-span}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{2200 \times 435}{0.8 \times 1000 \times 20} = \mathbf{59.8 \text{ mm}}$$

$$\xi = \frac{59.8}{294} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.2 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{mid-span}} = d - 0.4 \cdot x_m = 294 - 23.9 = \mathbf{270 \text{ mm.}}$$

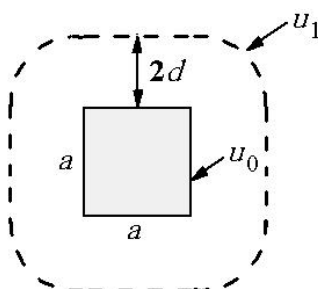
$$\text{Bending moment of slab at mid-span} = M_{Rd, \text{mid-span}} = A_{S,\text{Req},\text{mid-span}} \times f_{yd} \times z_{\text{mid-span}} =$$

$$2200 \times 435 \times 270 \times 10^{-6} = 32.9 \text{ kN.m.}$$

$$\mathbf{M_{Rd, mid-span} = 287 \text{ kN.m} \geq M_{Ed, mid-span} = 220 \text{ kN.m.} \text{..Ok}}$$

3.4 Preliminary check of punching

Control perimeters: ⁶



$$U_0 = 4a, U_0 = 1600 \text{ mm}$$

$$U_1 = 4a + 2\pi \cdot 2d, U_1 = 6174 \text{ mm}$$

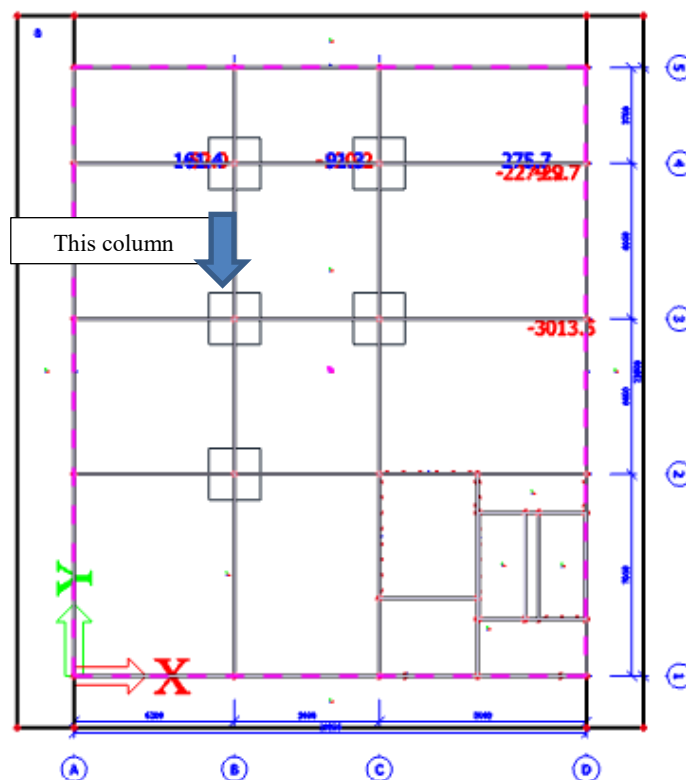


Figure 30 -The plan of foundation

⁶ Prochazka, J; Stemberk, P. *Concrete structures*, Praha: Ceske Vysoke Ucení Technické, 2009. S 97

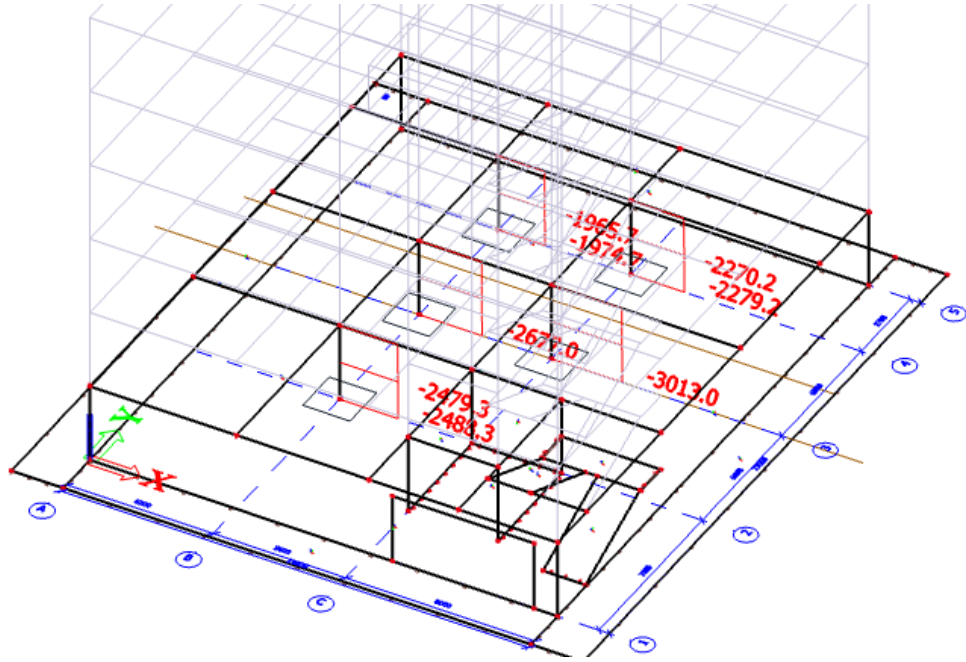


Figure 31 -Normal forces on columns

$d = h_s - c - \frac{\emptyset}{2} = 400 - 50 - \frac{12}{2} = 344 \text{ mm}$ the effective depth.

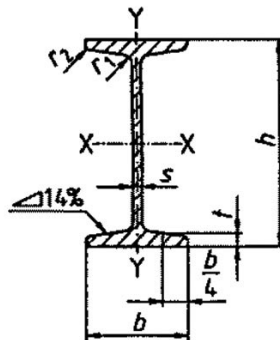
Punching shear resistance of slab and column without shear reinforcement in u_0

$$V_{Rd0} = \frac{0,4 \times (0,6(1 - 30/250)) \times 20 \times 0,344 \times 1,6}{1,15} = 2140 \geq 3013 \text{ kN the maximum punching shear stress}$$

is not exceeded, Fulfilled condition.

It is necessary to increase depth or insert steel beam.

To use 220 S235 material of steel⁷



Area = 3950 mm²

$$V_{Rd,s} = 3 \times 3.950 \times 102 = 1210 \text{ kN}$$

⁷ <https://online.ferona.cz/detail/32659/profil-i-valcovany-za-tepla-din-1025-1-i-220>, 5.11.2018, COPYRIGHT © 2017 FERONA A.S.

$$T = f_y / 2 = 235 / 1.15 / 2 = 102 \text{ MPa}$$

$$V_{Rd0} = 2140 + 1210 = 3350 \geq 3013 \text{ kN Fulfilled condition.}$$

Punching shear resistance of slab and column without shear reinforcement in u_1

$$V_{Rd,c} = C_{Rd,c} k (100 \rho_i f_{ck})^{1/3} \geq (v_{min} + k_1 \sigma_{cp}) \text{ where}$$

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2 = 1.7 \text{ ok}$$

$$\rho_i = \sqrt{\rho_{iy} \cdot \rho_{iz}} \leq 0.02$$

$$C_{Rd,c} = 0.18 / 1.5 = 0.1$$

$$K_1 = 0.1$$

$$v_{min} = 0.035 \sqrt{k^3 \cdot f_{ck}} = 0.42$$

$$V_{Rd,c} = 970 \text{ kN} \geq N_{Ed} = 3013 \text{ kN} \text{ punching reinforcement necessary}$$

The design of punching reinforcement

$$V_{Rd,cs} = 0.75 V_{Rd,c} + V_{Rd,s} + (d/s_r) A_{sw} f_{ywd,ef} (1/u_1 d) \sin \alpha$$

Where A_{sw} the area of one perimeter of shear reinforcement around column.

s_r the radial spacing of perimeters of shear reinforcement (mm)

$$s_r \leq 0.75d, s_r \leq 0.2 \text{ spacing of studs}$$

$f_{ywd,ef}$ the effective design strength of the punching shear reinforcement

$$f_{ywd,ef} = 250 + 0.25d \leq f_{ywd} \text{ (MPa)} = 336 \text{ MPa} \leq 435 \text{ MPa}$$

d = the mean of effective depths

$\sin \alpha$ angle between stud and slab studs are vertical to the slab $\sin 90^\circ = 1$

$$V_{Rd,cs} = 0.75 V_{Rd,c} + 1210 + (d/s_r) A_{sw} f_{ywd,ef} (1/u_1 d) \sin \alpha$$

$$V_{Rd,cs} = 0.75 \times 965 + 1210 + (344/250) 20 \times 336$$

$$d_{sw} = 0.02$$

$$c_1 \quad \text{column}_1 \quad n = 9$$

$$V_{Rd,cs} = 3110 \text{ kN} \geq 3013 \text{ kN}$$

$$c_2 \quad \text{column}_2 \quad n = 4$$

$$V_{Rd,c} = 2460 \geq 2270 \text{ kN}$$

$$c_3 \quad \text{column}_3 \quad n = 8$$

$$V_{Rd} = 2580 \geq 2490 \text{ kN}$$

$$c_4 \quad \text{column}_4 \quad n = 6$$

$$V_{Rd} = 2720 \geq 2670 \text{ kN}$$

4. Beam design

4.1 The maximum bending moment from the beam kN.m

$$M_T = M_{\text{beam}} + m_{\text{slab}} + N_{\text{beam.e}}$$

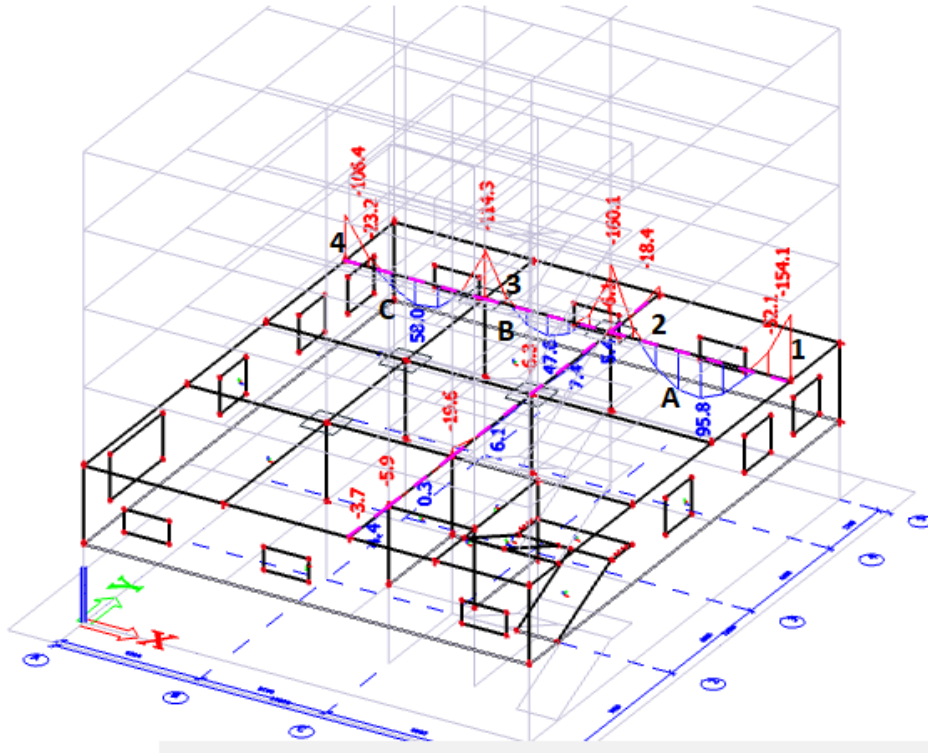


Figure 32 -The maximum bending moment on beam on the typical floor

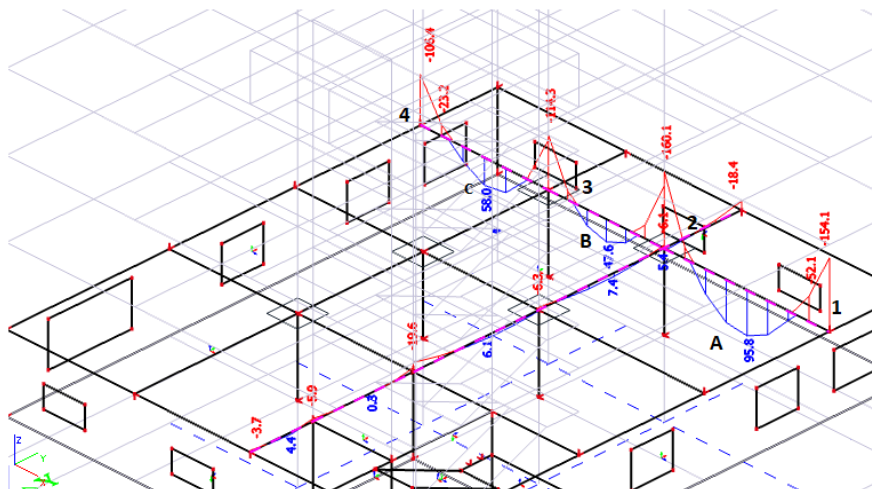


Figure 33 -The maximum bending moment on beam on the typical floor

4.2 The maximum shear forces V_z [kN]

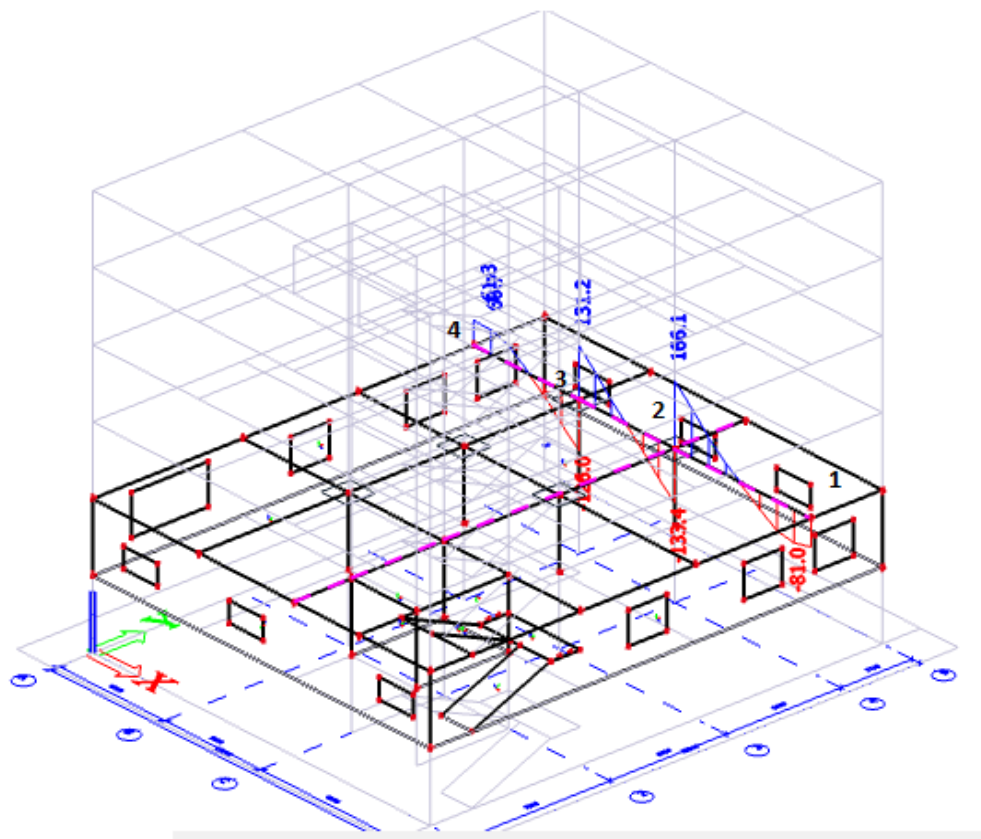


Figure 34 -The maximum shear forces on beam on the typical floor

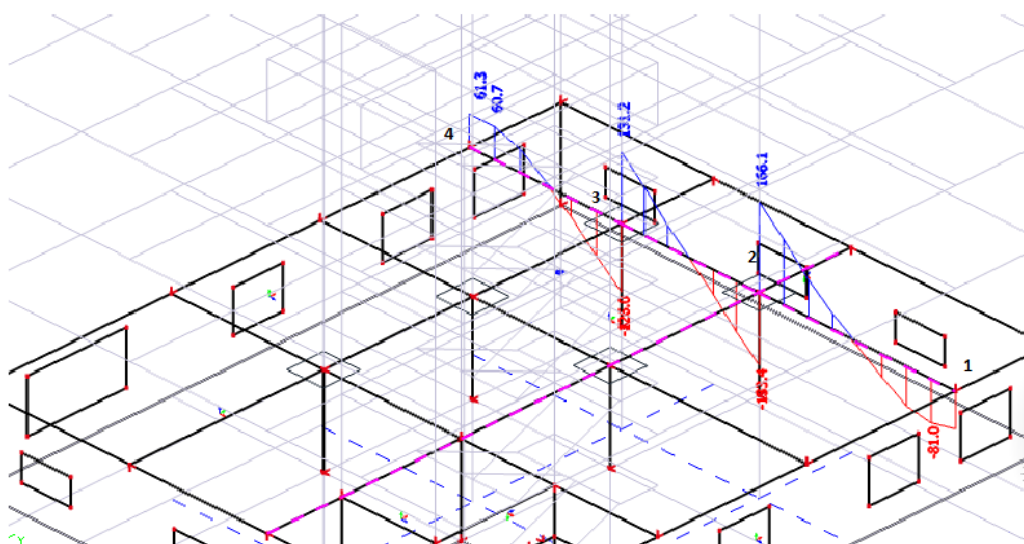


Figure 35 -The maximum shear forces on beam on the typical floor

4.3 Design of reinforcement

The design reinforcement of the typical floor

From support (1)

$M_{Ed, \max} = 154.1 \text{ kN.m.}$ (The maximum value) from the first combination CO1.

For mid-span support (A) from the first combination CO1.

$M_{Ed \text{ mid-span, max}} = 95.8 \text{ kN.m.}$ (The maximum value) from the first combination CO1.

Middle support (2)

$M_{Ed1, \max} = 160 \text{ kN.m.}$ (The maximum value) from the first combination CO1.

For mid-span middle support (B) from the first combination CO1.

$M_{Ed \text{ mid-span, max}} = 47.6 \text{ kN.m.}$ (The maximum value) from the first combination CO1.

Middle support (3)

$M_{Ed1, \max} = 114.3 \text{ kN.m}$ (The maximum value) from the first combination CO1.

For mid-span middle support (C)

$M_{Ed \text{ mid-span, max}} = 58 \text{ kN.m.}$ (The maximum value) from the first combination CO1.

From support (4)

$M_{Ed1, \max} = 106.4 \text{ kN.m}$ (The maximum value) from the first combination CO1.

The design reinforcement of beam

The effective b_{eff} of beams in middle support

The effective flange width b_{eff} depends on the distance l_o between consecutive zero moment points and on half the span b_1, b_2 at both sides of slabs.

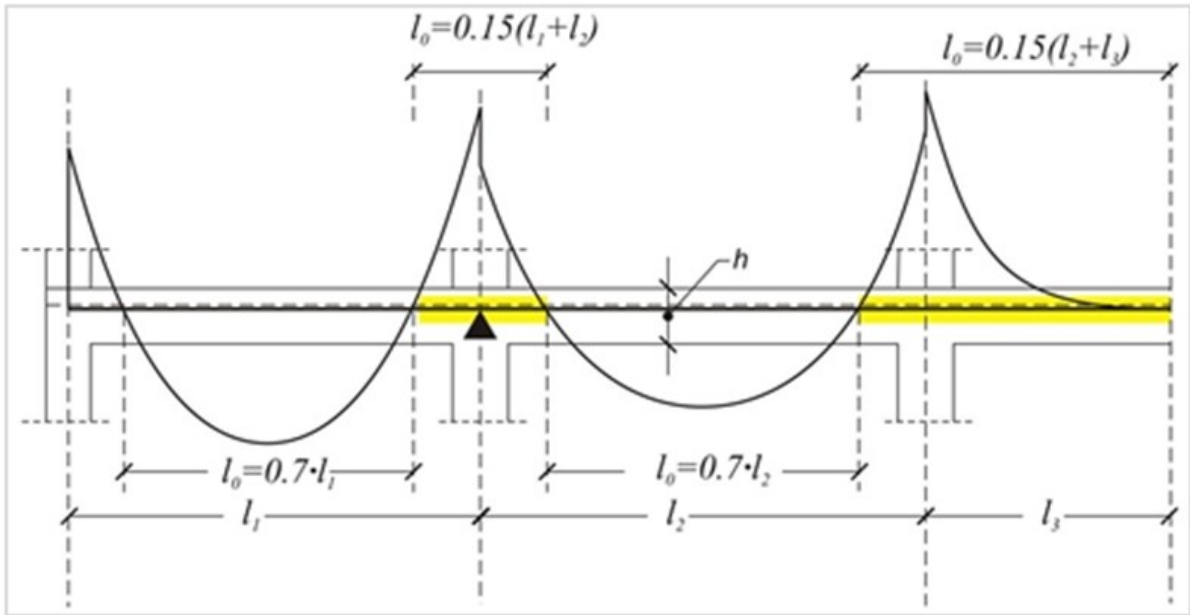
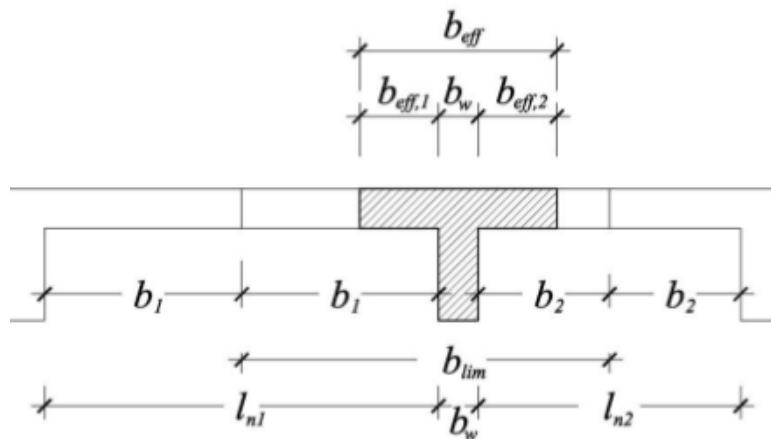


Figure 36 -Continuous beam of frames: lo⁸

Calculate the b_{eff} of the beam:

The effective flange width b_{eff} for a T beam,

Reinforced concrete floor systems normally consist of slabs and beams that are placed monolithically. As a result, the two parts act together to resist loads. In effect the beams have extra width at their tops (flanges) resulting on T-beam shaped beams.⁹



⁸ <https://www.buildinghow.com/en-us/Products/Books/Volume-B/Structural-model-and-Analysis/Structural-model>, 1.11.2018

⁹ <https://www.buildinghow.com/en-us/Products/Books/Volume-B/Structural-model-and-Analysis/Structural-model>, 5.10.2018

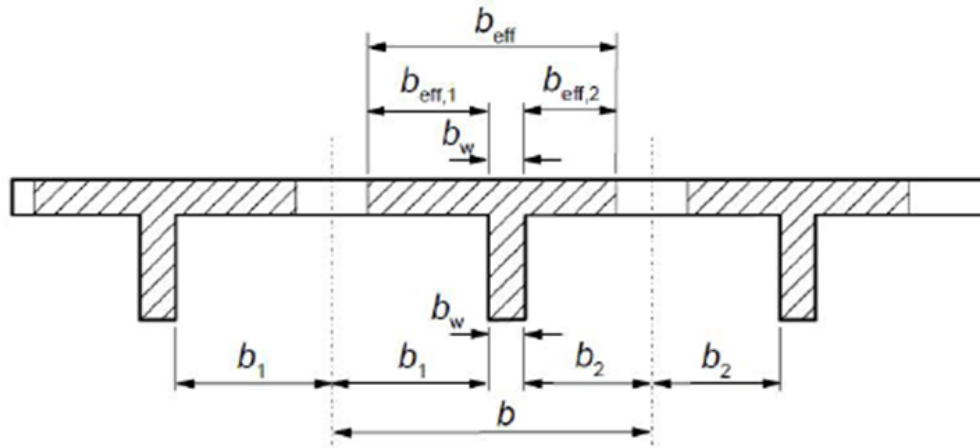


Figure 37 -T-shaped section¹⁰

$$b_{eff} = \sum b_{eff,i} + b_w \leq b \quad \text{where } b_{eff,i} = 0.2b_i + 0.1 l_o \leq 0.2 l_o$$

$$b_{eff,i} \leq b_i$$

$$l_o = 0.15(l_1 + l_2) = 2.04 \text{ m}$$

$$b_{eff} = b_w + b_{eff,1} + b_{eff,2} \leq b_{lim}$$

$$\text{Where } b_{eff,1} = 0.20 \cdot b_1 + 0.10 \cdot l_o \leq 0.20 \cdot l_o \text{ and } b_{eff,2} = 0.20 \cdot b_2 + 0.10 \cdot l_o \leq 0.20 \cdot l_o$$

$$b_1 = 5.6/2 = 2.8 \text{ m} \quad b_2 = 6.8/2 = 3.4 \text{ m}$$

$$b_{lim} = b_w + b_1 + b_2 = 0.25 + 2.8 + 3.4 = 6.45 \text{ m}$$

The effective width is equal to:

$$b_{eff,1} = \min(0.2 b_1 + 0.1 l_o, 0.2 l_o) = \min(0.56 + 0.204, 0.408) = \min(0.764, 0.408)$$

$$b_{eff,1} = 0.408 \text{ m} = b_{eff,2}$$

$$b_{eff} = \min(b_w + b_{eff,1} + b_{eff,2}, b_{lim}) = \min(0.3 + 0.408 + 0.408, 6.45)$$

$$b_{eff} = 1.11 \text{ m}$$

The effective b_{eff} of beams in support

$$b_{eff} = b_w = 300 \text{ mm}$$

Support (1):

$$\mu_{support,1} = \frac{M_{Ed,support1}}{b_B \cdot d_B^2 \cdot f_{cd}} = \frac{154.1}{0.3 \times 0.457^2 \times 20 \times 10^3} \approx 0.13, \text{ according to } \mu \rightarrow \zeta = 0.93 \text{ from design}$$

table for rectangular cross section loaded by bending.

μ .. Relative bending moment.

¹⁰ <https://www.eng-tips.com/viewthread.cfm?qid=429624>, 15.11.2018

d_B ... effective height of beam, $d_B = h_B - \frac{\emptyset}{2} - \emptyset_{SW} - c = 500 - \frac{20}{2} - 8 - 25 = \mathbf{457 \text{ mm}}$.

The required reinforcement: $A_{S,\text{support},1} = \frac{M_{Ed,\text{support},1}}{\zeta \cdot d_B \cdot f_{yd}} = \frac{154.1}{0.93 \times 0.457 \times 435 \times 10^3} =$

$A_{S,\text{support},1} = \mathbf{833 \text{ mm}^2}$.

The area of longitudinal tension reinforcement should not be taken as less than $A_{S,\text{min}}$.

$A_{S,\text{min}} = 0.26 \frac{f_{ctm}}{f_{yk}} b_t d = \frac{2.9}{500 \times 10^3} 0.3 \times 0.5 = A_{S,\text{support},1} = \mathbf{870 \text{ mm}^2}$.

3 bars with 20 Ø diameter, $A_{S,\text{Prov},\text{support},1} = 3 \times \pi \times 10^2 = 942 \text{ mm}^2$.

The compressed area of concrete: $x_{\text{support},1} = \frac{A_{S,\text{Prov},\text{support},1} \cdot f_{yd}}{0.8 \cdot b_B \cdot f_{cd}} = \frac{1257 \times 435}{0.8 \times 500 \times 20} = \mathbf{51.2 \text{ mm}}$.

Lever arm: $z_{\text{support},1} = d_B - 0.4 \cdot x_{\text{support},1} = 500 - 20.4 = \mathbf{479 \text{ mm}}$.

Bending moment of beam at support 1 = $M_{Rd, \text{support},1} = A_{S,\text{Req},\text{support},1} \times f_{yd} \times z_{\text{support},1} = 942 \times 435 \times 479 \times 10^{-6} = 196.4 \text{ kN.m}$.

$M_{Rd, \text{support},1} = 196.4 \text{ kN.m} \geq M_{Ed, \text{support},1} = 154.1 \text{ kN.m}$.Ok

(Mid-span A):

$\mu_{\text{mid-span},1} = \frac{M_{Ed,\text{mid-span},1}}{b_B \cdot d_B^2 \cdot f_{cd}} = \frac{95.8}{0.3 \times 0.457^2 \times 20 \times 10^3} \simeq 0.073$, according to $\mu \rightarrow \zeta = 0.964$ from

design table for rectangular cross section loaded by bending.

μ .. Relative bending moment.

d_B ... effective height of beam, $d_B = h_B - \frac{\emptyset}{2} - \emptyset_{SW} - c = 500 - \frac{20}{2} - 8 - 25 = \mathbf{457 \text{ mm}}$.

The required reinforcement: $A_{S,\text{mid-span},1} = \frac{M_{Ed,\text{mid-span},1}}{\zeta \cdot d_B \cdot f_{yd}} = \frac{95.8}{0.964 \times 0.457 \times 435 \times 10^3} =$

$A_{S,\text{mid-span},1} = \mathbf{499 \text{ mm}^2}$.

3 bars with 16 Ø diameter, $A_{S,\text{Prov},\text{mid-span},1} = 3 \times \pi \times 8^2 = 603 \text{ mm}^2$.

The compressed area of concrete: $x_{\text{mid-span},1} = \frac{A_{S,\text{Prov},\text{midspan},1} \cdot f_{yd}}{0.8 \cdot b_B \cdot f_{cd}} = \frac{603 \times 435}{0.8 \times 300 \times 20} = \mathbf{54,6 \text{ mm}}$.

Lever arm: $z_{\text{support},1} = d_B - 0.4 \cdot x_{\text{mid-span},1} = 457 - 21,8 = \mathbf{435.1 \text{ mm}}$.

Bending moment of beam at mid-span 1 = $M_{Rd, \text{mid-span},1} = A_{S,\text{Req},\text{mid-span},1} \times f_{yd} \times$

$z_{\text{mid-span},1} = 603 \times 435 \times 435.1 \times 10^{-6} = 114.1 \text{ kN.m}$.

$M_{Rd,\text{mid-span},1} = 114.1 \text{ kN.m} \geq M_{Ed, \text{mid-span},1} = 95.8 \text{ kN.m}$.Ok

Middle Support:

$$\mu_{\text{middle-support}} = \frac{M_{\text{Ed,red,middle support,1}}}{b \cdot d_B^2 \cdot f_{cd}} = \frac{160}{1.11 \times 0.457^2 \times 20 \times 10^3} \approx 0.03, \text{ according to } \mu \rightarrow$$

$\zeta=0.985$ from design table for rectangular cross section loaded by bending.

μ .. Relative bending moment.

$$d_B \dots \text{effective height of beam, } d_B = h_B - \frac{\emptyset}{2} - \emptyset_{SW} - c = 500 - \frac{20}{2} - 8 - 25 = 457 \text{ mm.}$$

The required reinforcement: $A_{S,\text{Req,s middle support,1}} =$

$$\frac{M_{\text{Ed,middle support,2}}}{\zeta \cdot d_B \cdot F_{yd}} = \frac{160}{0.985 \times 0.457 \times 435 \times 10^3} = 817 \text{ mm}^2.$$

$$\text{3 bars with 20 } \emptyset \text{ diameter, } A_{S,\text{Prov,middle support 1}} = 3 \times \pi \times 10^2 = 942 \text{ mm}^2.$$

$$\text{The compressed area of concrete: } x_{\text{middle support,1}} = \frac{A_{S,\text{Prov,middle support,1}} \times F_{yd}}{0.8 \cdot b \cdot F_{yd}}$$

$$\frac{942 \times 435}{0.8 \times 300 \times 20} = 85,3 \text{ mm.}$$

$$\text{Lever arm: } z_{\text{middle support 2}} = d_B - 0.4 \cdot x_{\text{middle support,1}} = 457 - 34,14 = 422,8 \text{ mm.}$$

$$\text{Bending moment of beam at middle support,1} = M_{\text{Rd, middle support, 1}} = A_{S,\text{Req,middle support,1}} \times f_{yd} \times$$

$$z_{\text{middle support,1}} = 942 \times 435 \times 422,8 \times 10^{-6} = \text{kN.m.}$$

$$M_{\text{Rd, middle support,1}} = 173.4 \text{ kN.m} \geq M_{\text{Ed, middle support,1}} = 160 \text{ kN.m. Ok.}$$

(Mid-span B, C):

$$\mu_{\text{mid-span,2}} = \frac{M_{\text{Ed,mid-span2}}}{b_B \cdot d_B^2 \cdot f_{cd}} = \frac{47.6}{0.3 \times 0.457^2 \times 20 \times 10^3} \approx 0.04, \text{ according to } \mu \rightarrow \zeta=0.980 \text{ from}$$

design table for rectangular cross section loaded by bending.

μ .. Relative bending moment.

$$d_B \dots \text{effective height of beam, } d_B = h_B - \frac{\emptyset}{2} - \emptyset_{SW} - c = 500 - \frac{20}{2} - 8 - 25 = 457 \text{ mm.}$$

$$\text{The required reinforcement: } A_{S,\text{mid-span,1}} = \frac{M_{\text{Ed,mid-span2}}}{\zeta \cdot d_B \cdot f_{yd}} = \frac{47.6}{0.98 \times 0.457 \times 435 \times 10^3} =$$

$$A_{S,\text{mid-span,1}} = 245 \text{ mm}^2.$$

$$\text{2 bars with 16 } \emptyset \text{ diameter, } A_{S,\text{Prov,mid-span,1}} = 2 \times \pi \times 8^2 = 402 \text{ mm}^2.$$

$$\text{The compressed area of concrete: } x_{\text{mid-span,1}} = \frac{A_{S,\text{Prov,midspan,2}} \cdot f_{yd}}{0.8 \cdot b_{\text{eff}} \cdot f_{cd}} = \frac{402 \times 435}{0.8 \times 1,11 \times 20} = 9,9 \text{ mm.}$$

$$\text{Lever arm: } z_{\text{support,1}} = d_B - 0.4 \cdot x_{\text{mid-span,1}} = 457 - 3,96 = 453 \text{ mm.}$$

$$\text{Bending moment of beam at mid-span 1} = M_{\text{Rd, mid-span1}} = A_{S,\text{Req,mid-span,2}} \times f_{yd} \times$$

$$z_{\text{mid-span,1}} = 402 \times 435 \times 453 \times 10^{-6} = 79,2 \text{ kN.m.}$$

$$M_{\text{Rd,mid-span 1}} = 79.2 \text{ kN.m} \geq M_{\text{Ed, mid-span,1}} = 47.6 \text{ kN.m. Ok}$$

Middle Support (3): the design of reinforcement same as middle support 1

(Mid- span 3): the design of reinforcement same as II mid-span.

Support (4):

$$\mu_{\text{support},4} = \frac{M_{\text{Ed},\text{support},4}}{b_B \cdot d_B^2 \cdot f_{cd}} = \frac{106.4}{0.3 \times 0.457^2 \times 20 \times 10^3} \simeq 0.09, \text{ according to } \mu$$

$\zeta=0.953$ from design table for rectangular cross section loaded by bending.

μ .. Relative bending moment.

$$d_B \dots \text{effective height of beam, } d_B = h_B - \frac{\emptyset}{2} - \emptyset_{\text{SW}} - c = 500 - \frac{20}{2} - 8 - 25 = \mathbf{457 \text{ mm.}}$$

$$\text{The required reinforcement: } A_{S,\text{support},4} = \frac{M_{\text{Ed},\text{support},4}}{\zeta \cdot d_B \cdot f_{yd}} = \frac{106.4}{0.953 \times 0.457 \times 435 \times 10^3} =$$

$$A_{S,\text{support},1} = \mathbf{560 \text{ mm}^2}.$$

$$\mathbf{4 \text{ bars with } 16 \emptyset \text{ diameter, } A_{S,\text{Prov},\text{support},4} = 4 \times \pi \times 10^2 = \mathbf{804 \text{ mm}^2}.$$

$$\text{The compressed area of concrete: } x_{\text{support},4} = \frac{A_{S,\text{Prov},\text{support},4} \cdot f_{yd}}{0.8 \cdot b_B \cdot f_{cd}} = \frac{804 \times 435}{0.8 \times 300 \times 20} = \mathbf{73 \text{ mm.}}$$

$$\text{Lever arm: } z_{\text{support},4} = d_B - 0.4 \cdot x_{\text{support},4} = 457 - 29.1 = \mathbf{427.8 \text{ mm.}}$$

$$\text{Bending moment of beam at support 4} = M_{\text{Rd},\text{support},4} = A_{S,\text{Req},\text{support},4} \times f_{yd} \times z_{\text{support},4} = 804 \times 435 \times 427.8 \times 10^{-6} = \mathbf{149.6 \text{ kN.m.}}$$

$$M_{\text{Rd},\text{support},4} = \mathbf{149.6 \text{ kN.m}} \geq M_{\text{Ed},\text{support},4} = \mathbf{106.4 \text{ kN.m.}} \text{Ok}$$

4.4 Beam-bending reinforcement – detailing rules

$$\xi = \frac{x}{d_B} \leq \min(\xi_{\text{bal},1} = \frac{700}{700 + f_{yd}} = 0.6, 0.45).$$

$$\text{Axial spacing of rebar: } S_A \leq \min(2h_B; 250) = (2 \times 300; 250) = S_A \leq \min(\mathbf{600; 250}).$$

$$\text{Clear spacing of rebar} = S_c \geq \max(20 \text{ mm}; 1.2\emptyset) = (20\text{mm}; 1.2\emptyset).$$

For support 1:

$$\frac{x_1}{d_B} \leq \min(\xi_{\text{bal},1} = 0.45) \Rightarrow \frac{51.3}{457} = 0.12 \leq 0.45 \text{ ok..}$$

$$S_{A,1} = \mathbf{180 \text{ mm}} \text{ axial spacing; } S_{c1} = \mathbf{160 \text{ mm.}} \text{ the clear spacing between bars. (With 2 stirrup).}$$

For midspan A:

$$\frac{x_{\text{midspan}}}{d_B} \leq \min(\xi_{\text{bal}} = 0.45) \Rightarrow \frac{54.6}{457} = 0.09 \leq 0.45 \text{ ok.}$$

$$S_{AA,\text{middle}} = \mathbf{180 \text{ mm}} \text{ axial spacing; } S_{c,A,\text{middle}} = \mathbf{160 \text{ mm.}} \text{ the clear spacing between bars.}$$

For middle support 2,3:

$$\frac{x_{\text{middle}}}{d_B} \leq \min(\xi_{\text{bal},1} = 0.45) \Rightarrow \frac{23}{457} = 0.05 \leq 0.45 \text{ ok.}$$

$$S_{A,2,\text{middle}} = \mathbf{180 \text{ mm}} \text{ axial spacing; } S_{c,2,\text{middle}} = \mathbf{160 \text{ mm.}} \text{ the clear spacing between bars.}$$

For midspan B, C:

$$\frac{x_{\text{midspan}}}{d_B} \leq \min(\xi_{\text{bal}} = 0.45) \Rightarrow \frac{36.5}{457} = 0.08 \leq 0.45 \text{ ok.}$$

$S_{A,B, \text{middle}} = 180 \text{ mm}$ axial spacing; $S_{C,B, \text{middle}} = 160 \text{ mm}$. the clear spacing between bars

For support 4:

$$\frac{x_3}{d_B} \leq \min(\xi_{\text{bal},1} = 0.45) \Rightarrow \frac{73}{457} = 0.15 \leq 0.45 \text{ ok.}$$

$S_{A4} = 180 \text{ mm}$ axial spacing; $S_{C4} = 160 \text{ mm}$. the clear spacing between bars.

4.5 Design spacing of stirrups

stirrup $\phi_{\text{sw}} = 8 \text{ mm}$ with 2 legs, $n=2$, as a results cross-section area of reinforcement for 1

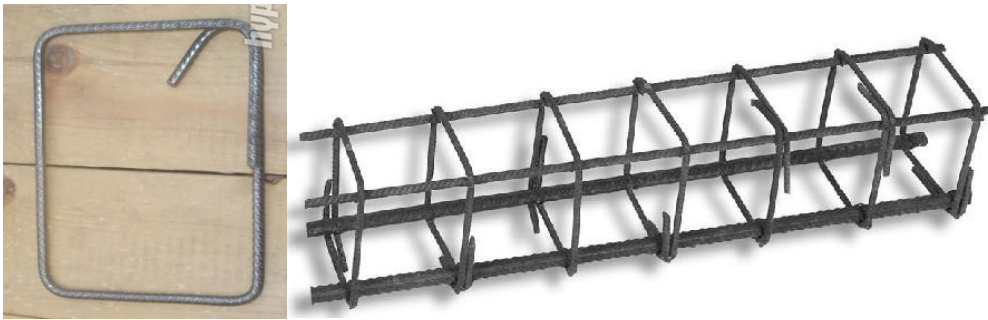


Figure 38 -The shape of stirrups

stirrup is:

$$\text{For spans: } A_{\text{sw}} = \frac{n\pi\phi_{\text{sw}}}{4} = \frac{2 \times \pi \times 8^2}{4} = 100.5 \text{ mm}^2 \quad A_{\text{sw}} = \frac{n\pi\phi_{\text{sw}}}{4} = \frac{2 \times \pi \times 8^2}{4} = 100.5 \text{ mm}^2$$

The spacing of stirrup for maximum shear forces

FOR SPAN A

$$S_1 \leq 0.75d_B = S_1 \leq 0.75 \times 457 = S_1 \leq 342 \text{ mm}, S_1 \leq \max(400) \text{ mm.}$$

$S_{1, \text{span1}} = 250 \text{ mm}$.

FOR SPAN B, C

$S_{1, \text{span2}} = 250 \text{ mm}$.

4.6 Shear Reinforcement ratio

$$\rho_{sw..min} = \frac{0.08 \times \sqrt{f_{ck}}}{f_{yk}} = \rho_{sw.min} = \frac{0.08 \times \sqrt{25}}{500} = 8 \times 10^{-4}.$$

For span A:

$$\rho_{sw.1} = \frac{A_{sw}}{b_B \times S_1} = \rho_{sw.1.span1} = \frac{100.1}{300 \times 300} = 1.1 \times 10^{-3} > \rho_{sw..min} = 8 \times 10^{-4}. \text{ ...Ok}$$

$$\rho_{sw.2} = \frac{A_{sw}}{b_B \times S_2} = \rho_{sw.2.span1} = \frac{100.1}{300 \times 300} = 1.1 \times 10^{-3} > \rho_{sw..min} = 8 \times 10^{-4}. \text{ ...Ok}$$

For span B, C:

$$\rho_{sw.1} = \frac{A_{sw}}{b_B \times S_1} = \rho_{sw.1.span2} = \frac{100.1}{300 \times 300} = 1.1 \times 10^{-3} > \rho_{sw..min} = 8 \times 10^{-4}. \text{ ...Ok}$$

$$\rho_{sw.2} = \frac{A_{sw}}{b_B \times S_2} = \rho_{sw.2.span2} = \frac{100.1}{300 \times 300} = 1.1 \times 10^{-3} > \rho_{sw..min} = 8 \times 10^{-4}. \text{ ...Ok}$$

Shear reinforcement of the beam is designed and checked, if not checked we can increase \emptyset_{sw} , or decrease S_i .

5. Column design

5.1 Dimensions of columns

Dimensions of columns in typical floor 0.4m×0.4m.

Check the resistance: $N_{Rd} = 0.8 \times A_C \times F_{cd} + A_s \times \sigma_s \dots$ where $F_{cd} = 20$, $\sigma_s = 400$.

$A_s = 2\%$, $A_C = 0.02 \times A_C$

$A_C = 400 \times 400 = 160000 \text{ mm}^2$ (the minimum area of column should be).

$N_{Rd} = 0.8 \times 160000 \times 20 + 0.02 \times 160000 \times 400 =$

$N_{Rd} = 3840 \text{ kN} \geq N_{Ed} = 3013 \text{ kN} \dots \text{Ok}$ $N_{Rd} = 130 \% \text{ of } N_{Ed}$ (safe sized of design).

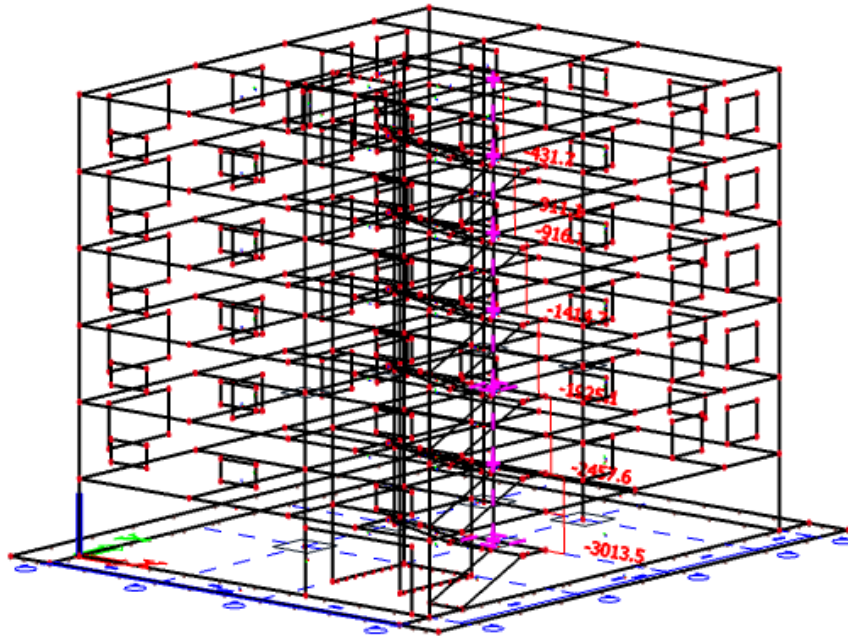


Figure 39 -Maximum normal forces [kN]

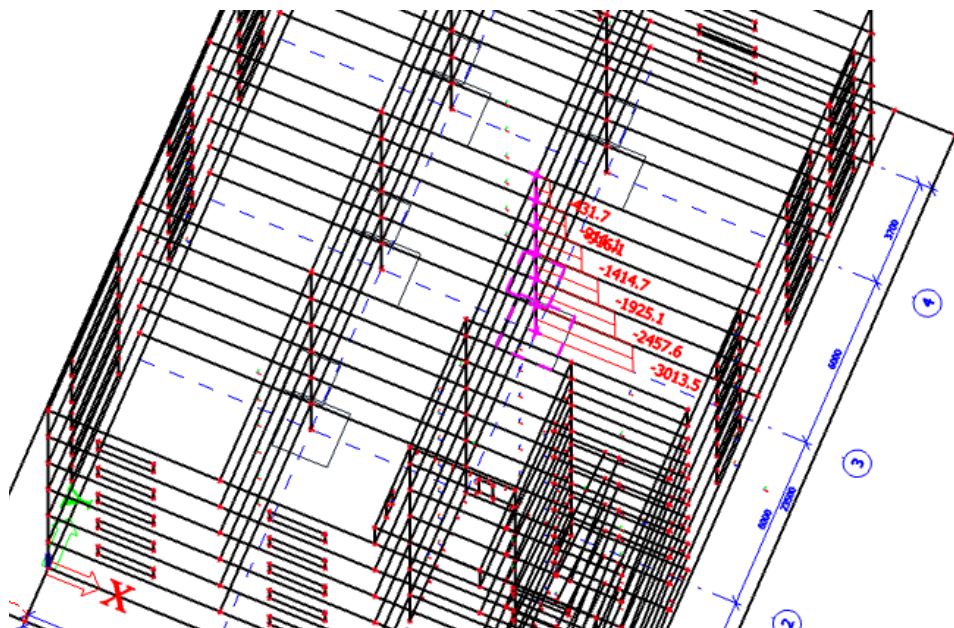


Figure 40 -Maximum normal forces [kN]

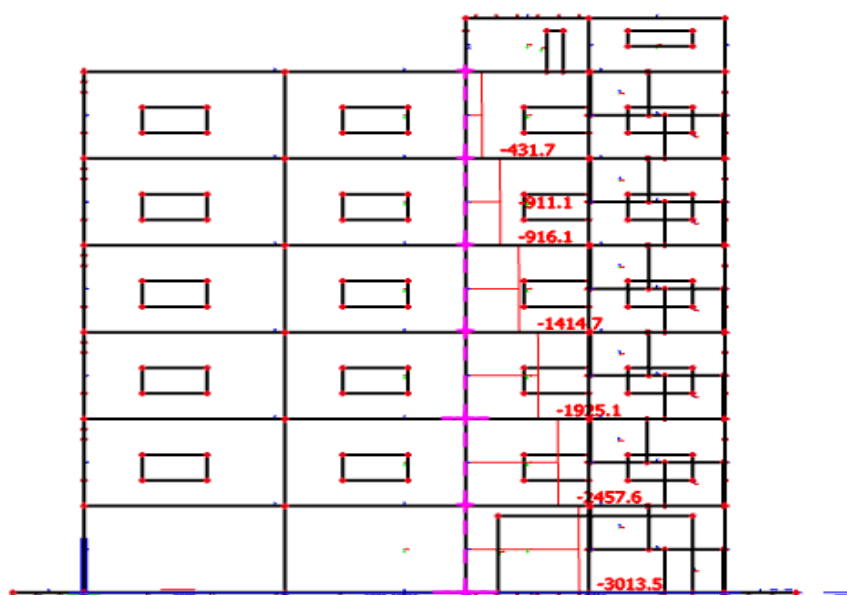


Figure 41 -Maximum normal forces [kN]

5.2 Column-slenderness

$\lambda = \frac{L}{i} \Rightarrow \lambda \dots$ slenderness of column.

$i = \sqrt{\frac{I}{A_c}}$ clear height of the column; $L = 0.8 h_c$ effective length of column.

h_c = the clear height of the column.

$I = \frac{1}{12} \times b_{\text{column}} \times h_{\text{column}}^3$ moment of inertia.

The height of floor is $h=3.4$, the depth of beam is $d=500\text{mm}$ (slab + beam height),

The clear height of the column for

Each floor is $h_c = h_{\text{column}} - d_B$

$h_{\text{clear}} = 3.4 - 0.5 = 2.9 \text{ m}$ the clear height of column.

The effective length of column = $L_0 = 0.8 \times 2.9 = 2.32 \text{ m}$ the length of column

$A_c = 0.4 \times 0.4 = 0.16 \text{ m}^2$ Cross-sectional area of column

$I_{\text{column}} = \frac{1}{12} \times 0.4 \times 0.4^3 = 5.3 \times 10^{-3} \text{ m}^4$ moment of inertia.

$i = \sqrt{\frac{I}{A_c}} = \sqrt{\frac{5.3 \times 10^{-3}}{0.16}} = 0.182 \text{ m}$ radius of gyration

column slenderness

$$\lambda = \frac{L_0}{i} \quad \lambda = \frac{2.32}{0.182} \quad \lambda = 12.75$$

5.3 Limiting of slenderness

Calculate the slenderness of column and check it, with the limiting value:

$$\lambda_{\text{lim}} = \frac{20 A_{B,C}}{\sqrt{n}} \leq 75$$

$A=0.7$...Effective of creep.

$B=1.1$... effective of reinforcement.

C ... effective of bending moments

$n = \frac{N_{Ed}}{A_c \times f_{cd}}$...Relative normal force

From software SCIA the maximum normal $N_{Ed} = 3013 \text{ kN}$.

$n = \frac{3013}{0.4^2 \times 20} = 0.941$ the relative maximum normal force, see fig.40-41

Calculate of C factor (effective of bending moment),

$C = 1.7 - \frac{M_{01}}{M_{02}}$; where M_{01} , M_{02} are the maximum values of bending moment in head and

foot of the column. $|M_{02}| > |M_{01}|$

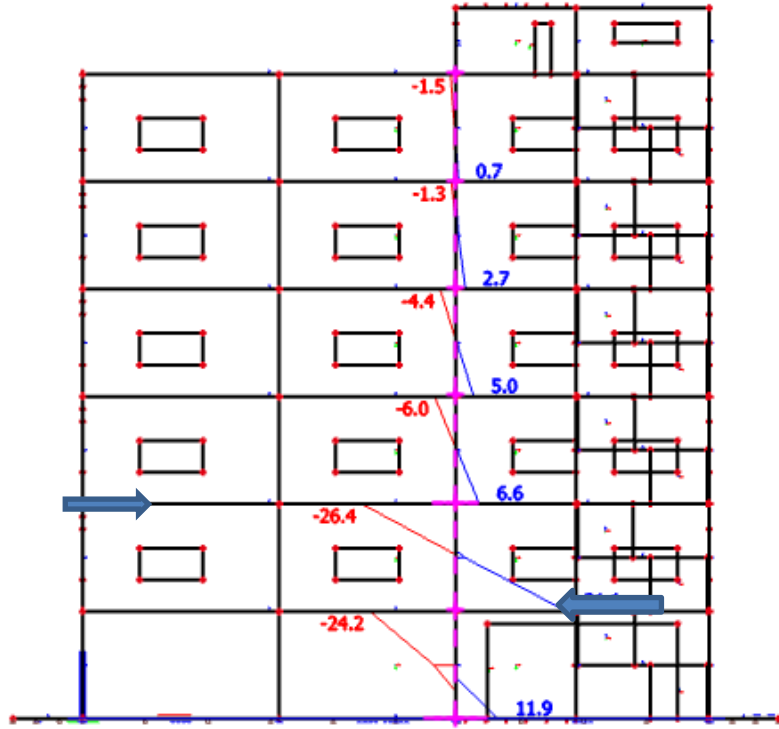


Figure 42 -Maximum bending moment

$$C = 1.7 \frac{M_{01}}{M_{02}}$$

$$C = 1.7 + \frac{26.4}{31.1} = 2.54$$

$$\lambda_{lim} = \frac{20 A.B.C}{\sqrt{n}} \leq 75 = \lambda_{lim} = \frac{20 \times 0.7 \times 1.1 \times 2.54}{\sqrt{0.941}} \leq 75 = \lambda_{lim} = 40.4 \text{ ok}$$

The slenderness of column according to euro-code

$\lambda_{lim} \geq \lambda$ the column robust

$\lambda_{lim} = 40.4 \geq \lambda = 14.5 \dots \text{ok}$

5.4 The bending moment in typical floor

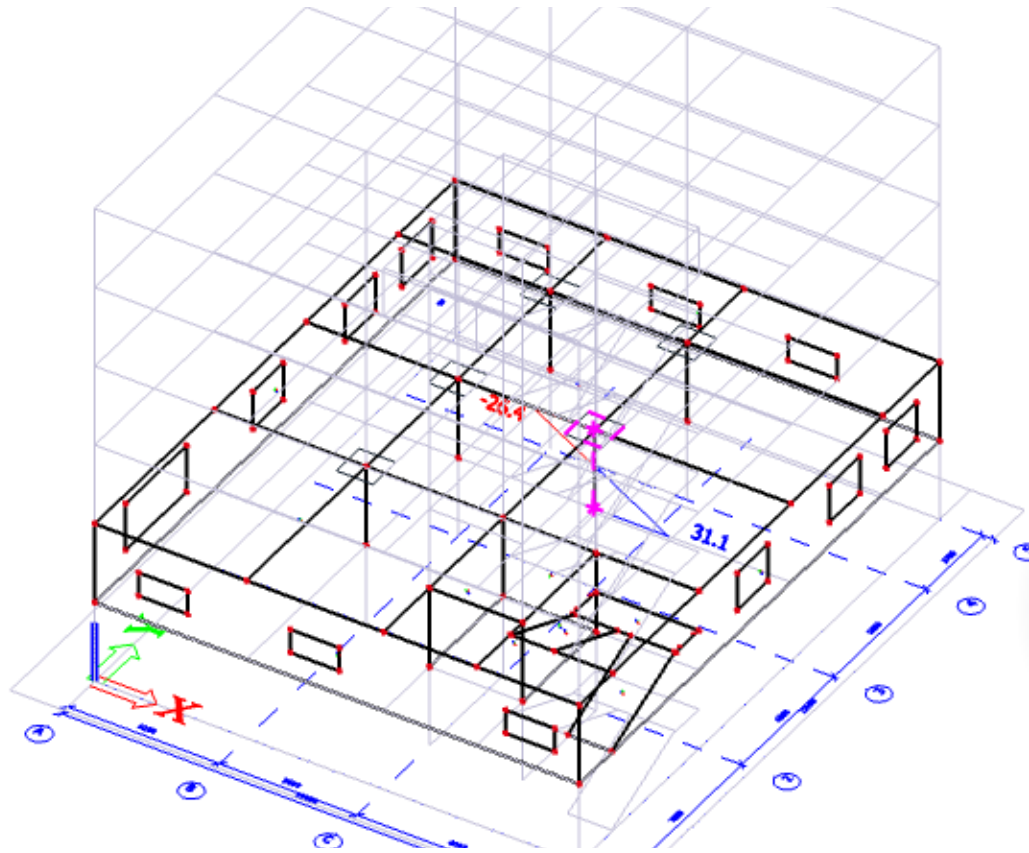


Figure 43 -Maximum normal forces [kN]

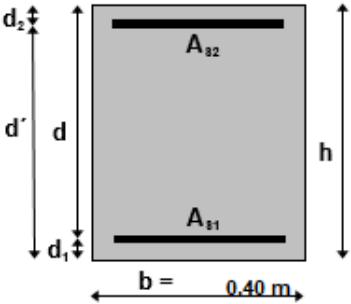
5.5 Design reinforcement of column

CONCRETE C30/37 $f_{ck} = 30 \text{ MPa}$ $f_{cd} = 20.0 \text{ MPa}$ $\epsilon_{yd} = 2.174 \text{ ‰}$
STEEL B500B $\gamma_c = 1.5$ $f_{yd} = 434.8 \text{ MPa}$ $\epsilon_{bal,1} = 0.617$
 $f_{yk} = 500 \text{ MPa}$ $\sigma_s = 400 \text{ MPa}$ $\epsilon_{bal,2} = 2.639$
 $\gamma_s = 1.15$ $x_{bal,1} = 0.221 \text{ m}$ $\epsilon_{lim} = 0.617$
 $x_{bal,2} = 0.108 \text{ m}$ $\epsilon_{lim1} = 2.639$

LOADING
 $N_{Ed} = 3013 \text{ kN}$
 $M_{Ed} = 31.1 \text{ kNm}$ compression with + sign

PRELIMINARY DIMENSION DESIGN
 % of reinforcement 2.00 %
 area of a rebar 0.126 m²
 h/b ratio 1
 Design $b = 0.354 \text{ m}$
 $h = 0.354 \text{ m}$

Design $b = 0.4 \text{ m}$
 $h = 0.4 \text{ m}$



PRELIMINARY REINFORCEMENT DESIGN
 cover 25 mm
 Ø Secondary RF 6 mm
 Ø Main RF 20 mm
 $d_1 = d_2 = 41 \text{ mm}$
 $d = 0.359 \text{ m}$
 $e_{Ed} = 0.010 \text{ m}$
 $e_0 = 0.020 \text{ m}$
 type of loading
 $N_{o,bal} = 1417.3 \text{ kN}$
 $|N_{Ed}| = 3013.0 \text{ kN} > N_{o,bal} = 1417.3 \text{ kN} \Rightarrow$ compression (small eccentricity)
 area IV.

| Design of RF area | mm ² | 226 | 226 |
|---------------------|-----------------|----------|----------|
| chosen RF | | A_{s1} | A_{s2} |
| diameter of a rebar | mm | 20 | 20 |
| number of rebars | ks | 2 | 2 |
| RF area A_s | mm ² | 628 | 628 |
| $A_{s,min}$ | mm ² | 261 | 346 |
| $A_{s,max}$ | mm ² | 6400 | 6400 |
| d/d' | m | 0.365 | 0.365 |
| d_1/d_2 | m | 0.035 | 0.035 |
| z_1/z_2 | m | 0.138 | 0.138 |
| F_{s1}/F_{s2} | kN | 273.2 | 273.2 |
| ΔF_s | kN | 0.0 | |

CHECK

| | |
|--|------|
| $N_{Rd} = 3266.6 \text{ kN} > N_{Ed} = 3013.0 \text{ kN} \Rightarrow$ tension (big eccentricity) | GOOD |
| $M_{Ed} = 31.1 \text{ kNm} < M_{Rd} = 116.5 \text{ kNm}$ | |
| $> M_{Rd} = 0.0 \text{ kNm}$ | GOOD |

ID-Point (0)

Compression uniformly distributed over the whole cross-section (pure compression)

POINTS OF INT. DIAGRAM

point 0

$$\begin{aligned} N_{Rd,0} &= -3702.7 \text{ kN} \\ M_{Rd,0} &= 0.0 \text{ kNm} \end{aligned}$$

between point 0 - 1 na úrovni 0'

$$\begin{aligned} \sigma_{S1} &= 137.1 \text{ Mpa} \\ \sigma_{S2} &= 434.8 \text{ Mpa} \\ N_{Rd} &= -3062.7 \text{ kN} \\ M_{Rd} &= 109.7 \text{ kNm} \end{aligned} \quad k = 1.164$$

point 1

$$\begin{aligned} N_{Rd,1} &= -2609.2 \text{ kN} \\ M_{Rd,1} &= 163.8 \text{ kNm} \\ d &= 0.365 \geq \xi_{bal,2} \cdot d_2 = 0.092 \end{aligned}$$

between point 1 - 2, $x = (d + \xi_{lim} \cdot d)/2$

$$\begin{aligned} x &= 0.295 \text{ m} \\ \sigma_{S1} &= 165.9 \text{ Mpa} \\ N_{Rd} &= -2057.4 \text{ kN} \\ M_{Rd} &= 206.9 \text{ kNm} \end{aligned}$$

Point 2

$$\begin{aligned} N_{Rd,bal} &= -1441.0 \text{ kN} \\ M_{Rd,bal} &= 233.8 \text{ kNm} \\ \xi_{bal,1} \cdot d &= 0.225 \geq \xi_{bal,2} \cdot d_2 = 0.092 \end{aligned}$$

Bod 0'

$$N_{Rd,0'} = -3062.7 \text{ kN}$$

Bod mezi 0 a 1 na úrovni 0'

$$\begin{aligned} \sigma_{S1} &= 137.1 \text{ Mpa} \\ \sigma_{S2} &= 434.8 \text{ Mpa} \\ N_{Rd} &= -3062.7 \text{ kN} \\ M_{Rd} &= -109.7 \text{ kNm} \end{aligned} \quad k = 1.164$$

Bod 1'

$$\begin{aligned} N'_{Rd,1} &= -2609.2 \text{ kN} \\ M'_{Rd,1} &= -163.8 \text{ kNm} \\ d' &= 0.365 \geq \xi_{bal,2} \cdot d_1 = 0.092 \end{aligned}$$

Bod mezi 1' a 2', $x = (d' + \xi_{lim} \cdot d')/2$

$$\begin{aligned} x &= 0.295 \text{ m} \\ \sigma_{S2} &= 165.9 \text{ Mpa} \\ N_{Rd} &= -2057.4 \text{ kN} \\ M_{Rd} &= -206.9 \text{ kNm} \end{aligned}$$

Bod 2'

$$\begin{aligned} N'_{Rd,bal} &= -1441.0 \text{ kN} \\ M'_{Rd,bal} &= -233.8 \text{ kNm} \\ \xi_{bal,1} \cdot d' &= 0.225 \geq \xi_{bal,2} \cdot d_2 = 0.092 \end{aligned}$$

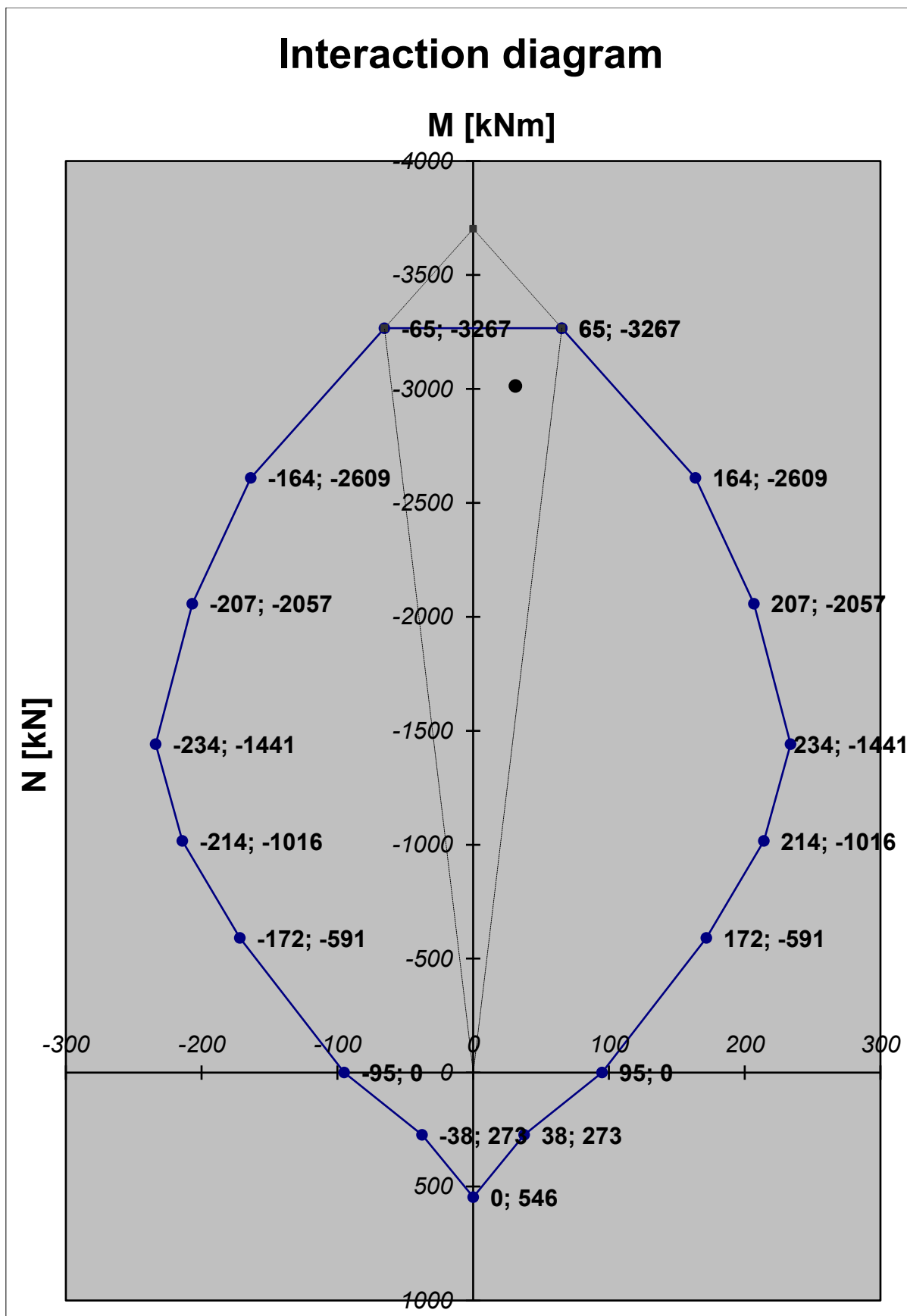


Figure 44 -Interaction diagram

6. Analysis of slab in 2nd floor

6.1 Upper part of slab

Bending moment on the support direction x

$$M_{Ed,S} = 70 \text{ kN.m.}$$

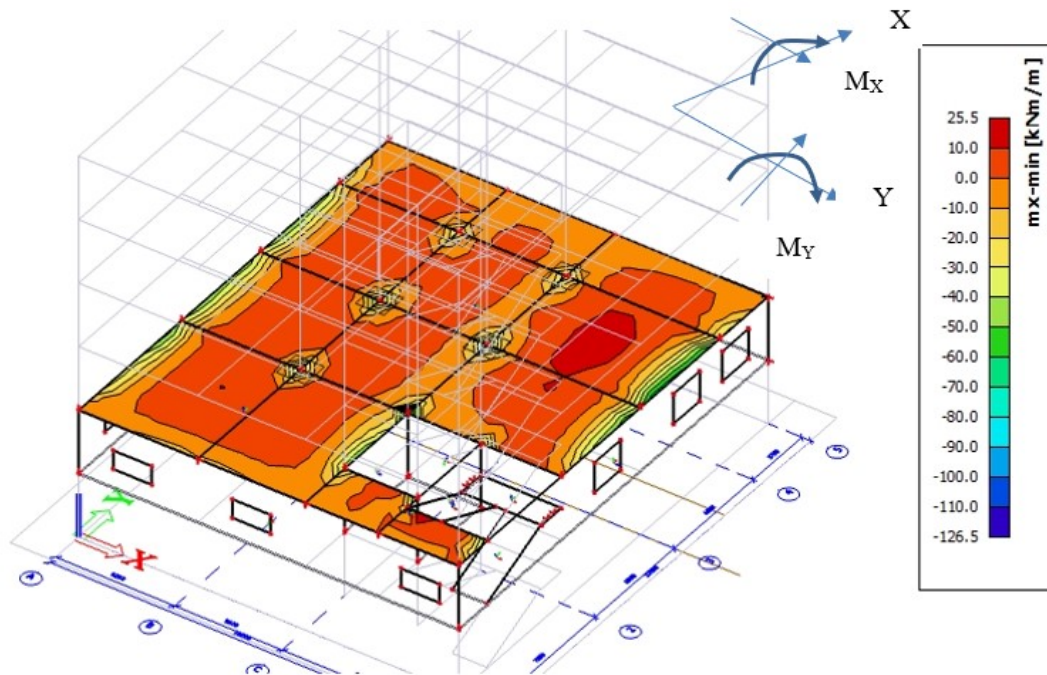


Figure 45 -Bending moment on the support from direction x

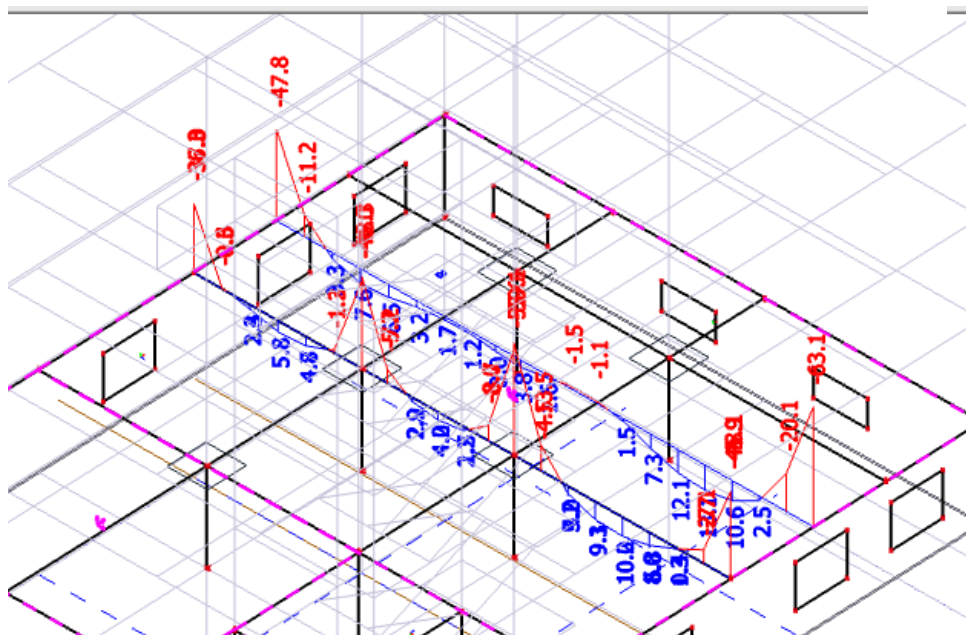


Figure 46 -Digram of bending moment on support direction x

The design of reinforcement of slab

$$d = h_s - c - \frac{\emptyset}{2} = 200 - 25 - \frac{12}{2} = 169 \text{ mm the effective depth.}$$

$$z = 0.9d, z = 0.9 \times 169 = 152 \text{ mm}$$

$$\text{The required reinforcement: } A_{S,\text{support}} = \frac{M_{\text{Ed},\text{support1}}}{z \cdot f_{yd}} = \frac{70}{152 \cdot 435} = 1055 \text{ mm}^2$$

$$A_{S,\text{support}} = 1289 \text{ mm}^2$$

$$\text{4 bars with 20 } \emptyset \text{ diameter, } A_{S,\text{Prov},\text{support}} = 5 \times \pi \times 10^2 = 1257 \text{ mm}^2$$

$$\text{Position of neutral axis: } x = \frac{A_{S,\text{Prov},\text{support}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{1257 \times 435}{0.8 \times 1000 \times 20} = 34.2 \text{ mm}$$

$$\xi = \frac{34.2}{169} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.2 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{support}} = d - 0.4 \cdot x_{\text{support}} = 169 - 13.6 = 155.3 \text{ mm.}$$

$$\begin{aligned} \text{Bending moment of slab at support} &= M_{\text{Rd},\text{support}} = A_{S,\text{Req},\text{support}} \times f_{yd} \times z_{\text{support}} \\ &= 1257 \times 435 \times 155.3 \times 10^{-6} = 39.3 \text{ kN.m.} \end{aligned}$$

$$M_{\text{Rd},\text{support}} = 84.9 \text{ kN.m} \geq M_{\text{Ed},\text{support}} = 70 \text{ kN.m. Ok}$$

Bending moment on the support direction y

$$M_{\text{Ed},S} = 62 \text{ kN.m.}$$

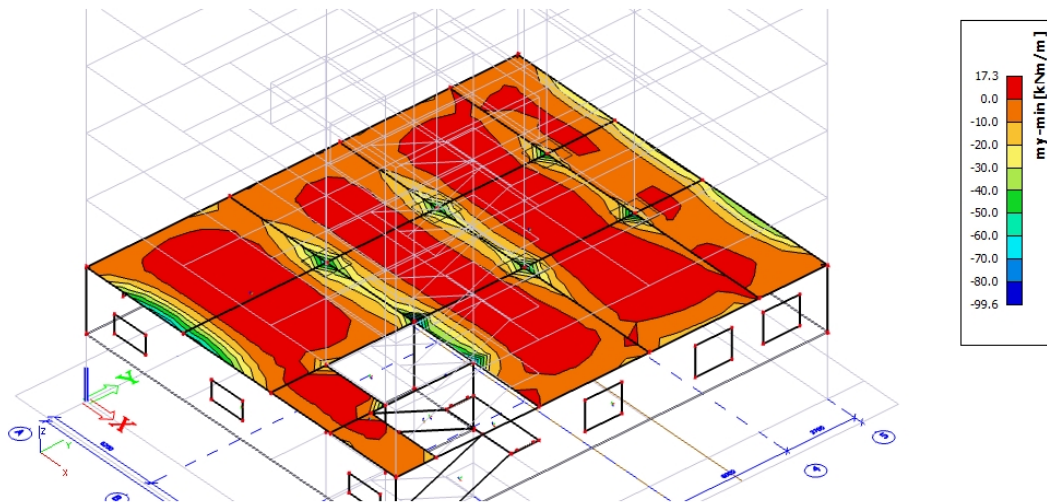


Figure 45 -Bending moment on the support from direction y

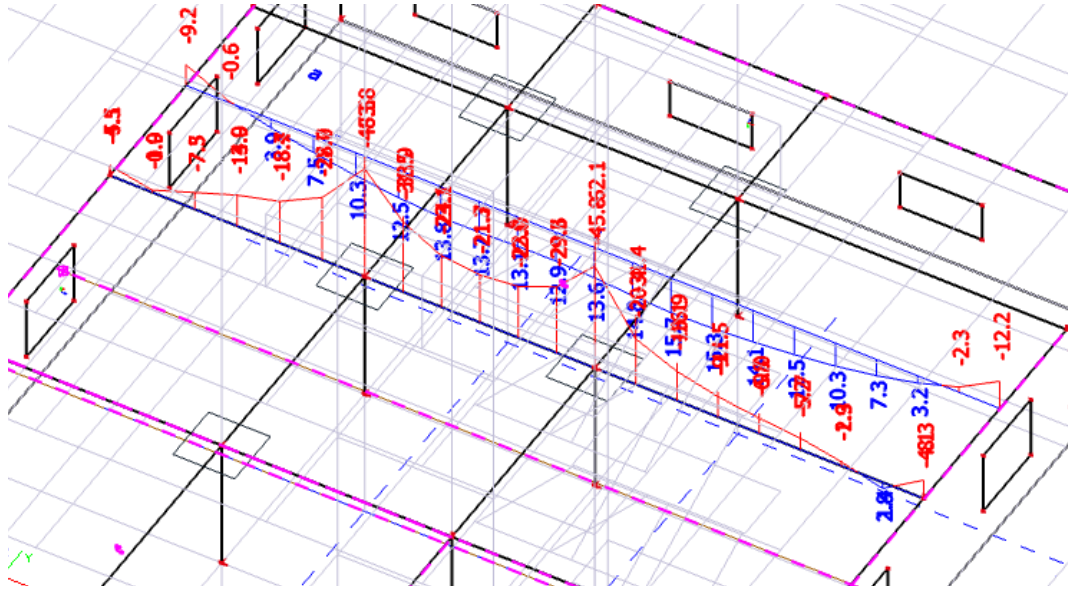


Figure 46 -Diagram of bending moment on support direction y

$d = h_s - c - \frac{\phi}{2} = 200 - 25 - \frac{12}{2} = 169 \text{ mm}$ the effective depth.

$z = 0.9d$, $z = 0.9 \times 169 = 152 \text{ mm}$

The required reinforcement: $A_{S,\text{support}} = \frac{M_{\text{Ed},\text{support}1}}{z \cdot f_{yd}} = \frac{63}{152 \cdot 435} = 952 \text{ mm}^2$

$A_{S,\text{support}} = 952 \text{ mm}^2$

4 bars with 20 Ø diameter, $A_{S,\text{Prov},\text{support}} = 5 \times \pi \times 10^2 = 1257 \text{ mm}^2$

Position of neutral axis: $x = \frac{A_{S,\text{Prov},\text{support}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{1257 \times 435}{0.8 \times 1000 \times 20} = 34.2 \text{ mm}$

$$\xi = \frac{34.2}{169} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$\xi = 0.2 \leq 0.6$ ok

Lever arm: $z_{\text{support}} = d - 0.4 \cdot x_{\text{support}} = 169 - 13.6 = 155.3 \text{ mm}$.

Bending moment of slab at support $= M_{\text{Rd},\text{support}} = A_{S,\text{Req},\text{support}} \times f_{yd} \times z_{\text{support}}$,
 $= 1257 \times 435 \times 155.3 \times 10^{-6} = 39.3 \text{ kN.m}$.

$M_{\text{Rd},\text{support}} = 84.9 \text{ kN.m} \geq M_{\text{Ed},\text{support}} = 62 \text{ kN.m}$. Ok

6.2 Lower part of slab

Bending moment from mid-span direction x

$M_{Ed,m} = 25 \text{ kN.m.}$

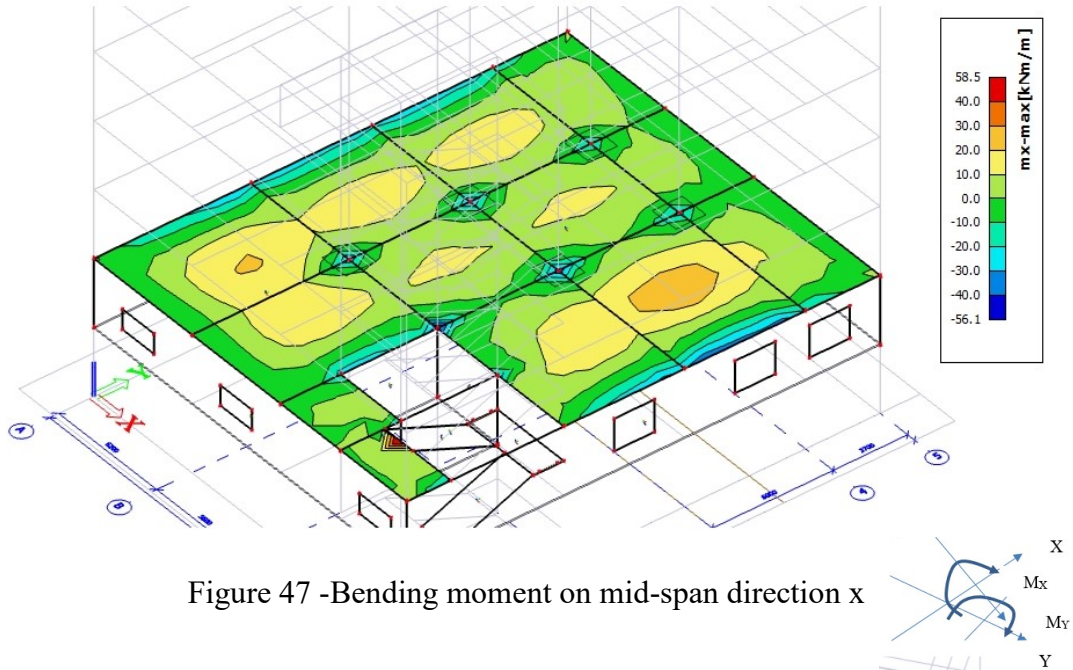


Figure 47 -Bending moment on mid-span direction x

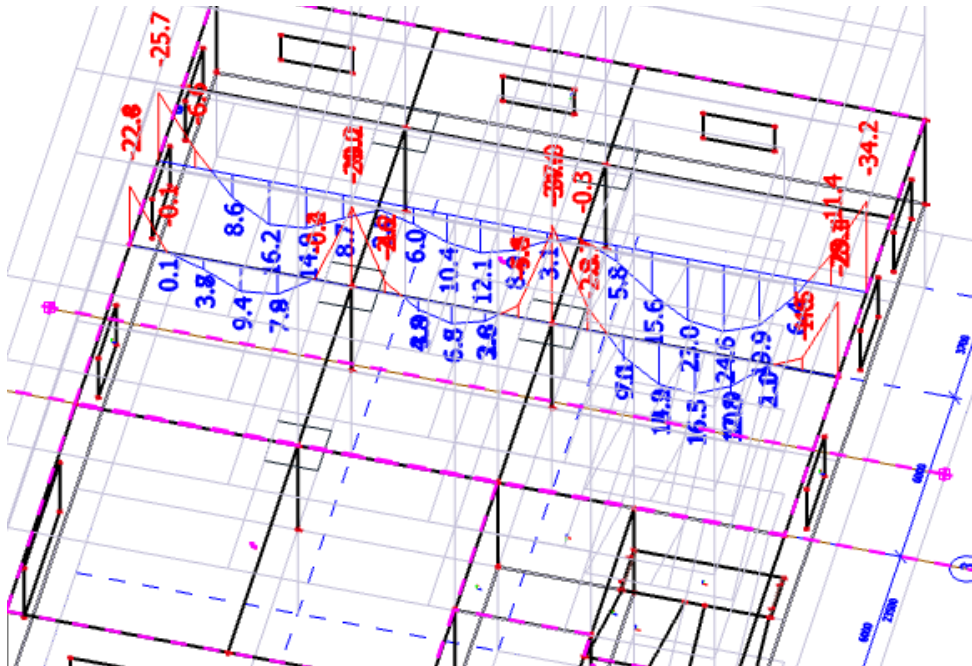


Figure 48 -Digram of bending moment on mid-span direction x

$$d = h_s - c - \frac{\emptyset}{2} = 200 - 25 - \frac{12}{2} = 169 \text{ mm the effective depth.}$$

$$z = 0.9d, z = 0.9 \times 169 = 152 \text{ mm}$$

$$\text{The required reinforcement: } A_{S, \text{mid-span}} = \frac{M_{Ed, \text{mid-span}}}{z \cdot f_{yd}} = \frac{25}{152 \times 435} = 378 \text{ mm}^2$$

$$A_{S, \text{mid-span}} = 454 \text{ mm}^2$$

$$\text{5 bars with 10 } \emptyset \text{ diameter, } A_{S, \text{Prov, mid-span}} = 5 \times \pi \times 5^2 = 390 \text{ mm}^2$$

$$\text{Position of neutral axis: } x = \frac{A_{S, \text{Prov, mid-span}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{462 \times 435}{0.8 \times 1000 \times 20} = 10 \text{ mm}$$

$$\xi = \frac{12.5}{169} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.075 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{mid-span}} = d - 0.4 \cdot x_m = 169 - 5 = 164 \text{ mm.}$$

$$\text{Bending moment of slab at mid-span} = M_{Rd, \text{mid-span}} = A_{S, \text{Req, mid-span}} \times f_{yd} \times z_{\text{mid-span}} =$$

$$462 \times 435 \times 164 \times 10^{-6} = 32.9 \text{ kN.m.}$$

$$M_{Rd, \text{mid-span}} = 29 \text{ kN.m} \geq M_{Ed, \text{mid-span}} = 25 \text{ kN.m. Ok}$$

The maximum bending moment from mid-span direction y

$$M_{Ed, m} = 27 \text{ kN.m.}$$

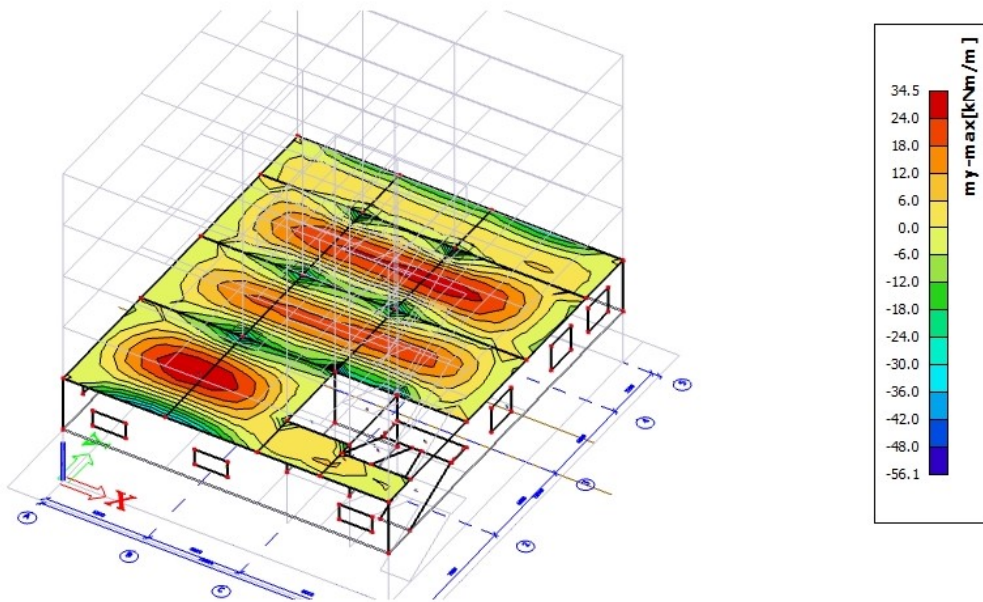


Figure 49 - Bending moment on mid-span direction y

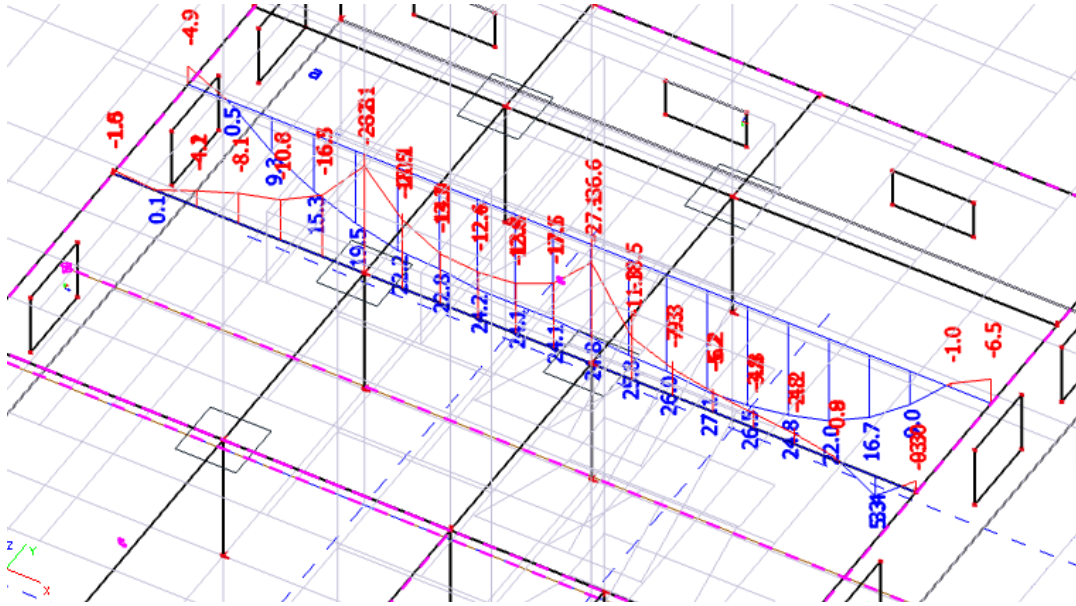


Figure 50 -Diagram of bending moment on mid-span direction y

$$d = h_s - c - \frac{\phi}{2} = 200 - 25 - \frac{12}{2} = \mathbf{169 \text{ mm}}$$
 the effective depth.

$$z = 0.9d, z = 0.9 \times 169 = 152 \text{ mm}$$

$$\text{The required reinforcement: } A_{S, \text{mid-span}} = \frac{M_{Ed, \text{mid-span}}}{z \cdot f_{yd}} = \frac{27}{152 \times 435} = 405 \text{ mm}^2$$

$$A_{S, \text{mid-span}} = \mathbf{405 \text{ mm}^2}$$

$$\mathbf{5 \text{ bars with } 10 \text{ } \phi \text{ diameter, } A_{S, \text{Prov, mid-span}} = 5 \times \pi \times 5^2 = 390 \text{ mm}^2}$$

$$\text{Position of neutral axis: } x = \frac{A_{S, \text{Prov, mid-span}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{462 \times 435}{0.8 \times 1000 \times 20} = \mathbf{10 \text{ mm}}$$

$$\xi = \frac{12.5}{169} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.075 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{mid-span}} = d - 0.4 \cdot x_m = 169 - 5 = \mathbf{164 \text{ mm.}}$$

$$\text{Bending moment of slab at mid-span} = M_{Rd, \text{mid-span}} = A_{S, \text{Req, mid-span}} \times f_{yd} \times z_{\text{mid-span}} = 462 \times 435 \times 164 \times 10^{-6} = 32.9 \text{ kN.m.}$$

$$\mathbf{M_{Rd, mid-span} = 29 \text{ kN.m} \geq M_{Ed, \text{mid-span}} = 27 \text{ kN.m. Ok}}$$

7. Staircase

7.1 Dimensions of steps:

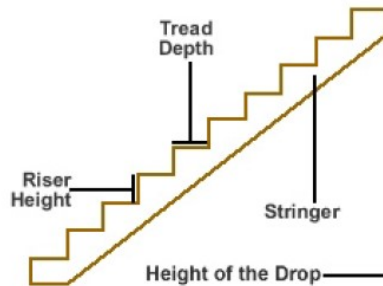


Figure 51 -Dimensions of staircase

The type of staircase two flight staircase

$2h + b = 630 \text{ mm}$, h = riser height, b = tread depth

$H_{\text{floor}} / 170 = 20 \text{ steps}$

$h = 170 \text{ mm}$, $b = 290 \text{ mm}$.

Stair slope = 30°

$2 \times 170 \text{ mm} + 290 \text{ mm} = 630 \text{ mm}$ dimensions of steps.

staircase wall = 300 mm per one of the arms. It is solved as monolithic

Reinforced concrete with concreted grades, thickness. staircases = 100mm.

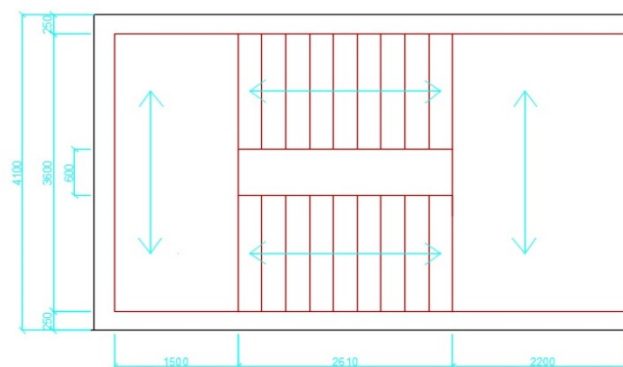


Figure 47 -Two – flight stairs carrying in two directions

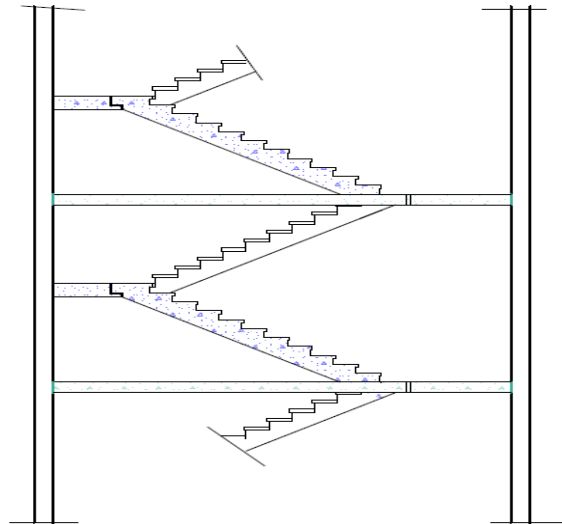


Figure 48 – Cross section of staircase

$$\text{Permanent load kN/m}^2 = \frac{0,17 \times 0,29}{2 \times 0,29} \times 22 = 1,9 \text{ kN/m}^2$$

$$\text{Self-weight} = 0.2 \times 25 = 5 \text{ kN/m}^2$$

$$\text{From the composition of stair} = 1.75 \text{ kN/m}^2 \times 1.35 = 2.37 \text{ kN/m}^2$$

$$\text{Variable load} = 3 \text{ kN/m}^2 \times 1.5 = 4.5 \text{ kN/m}^2$$

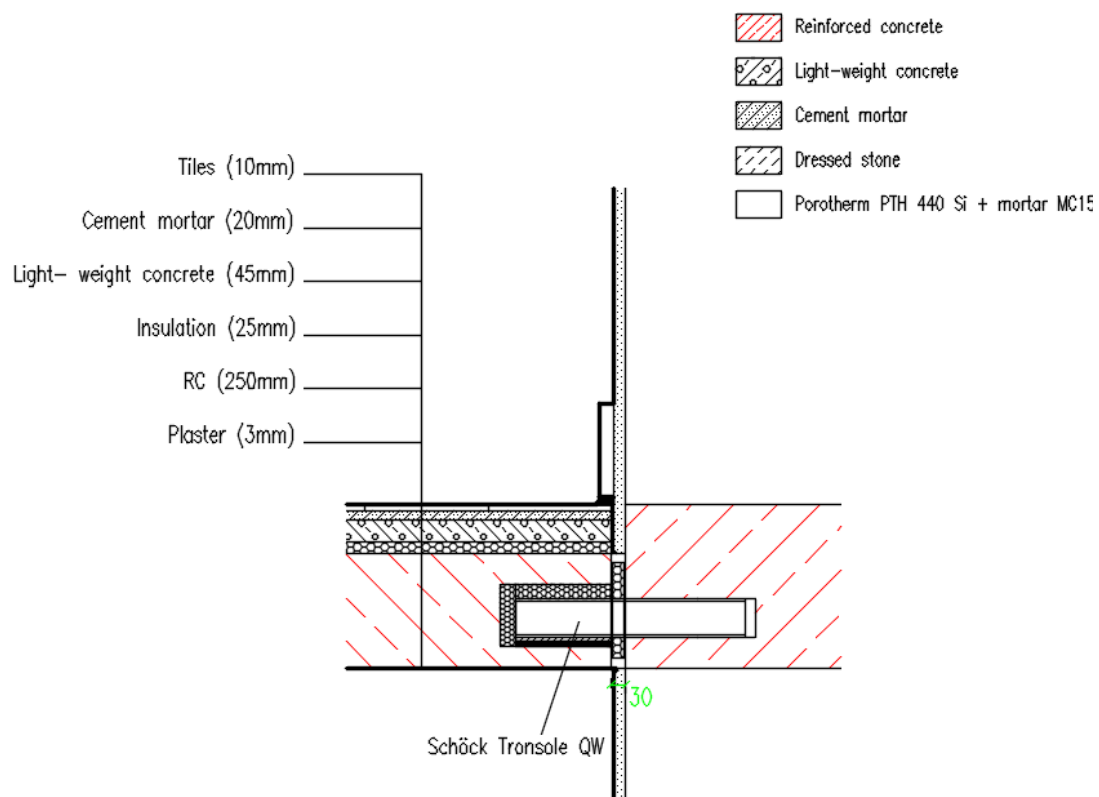


Figure 49 - Composition of staircase

7.2 Design of reinforcement

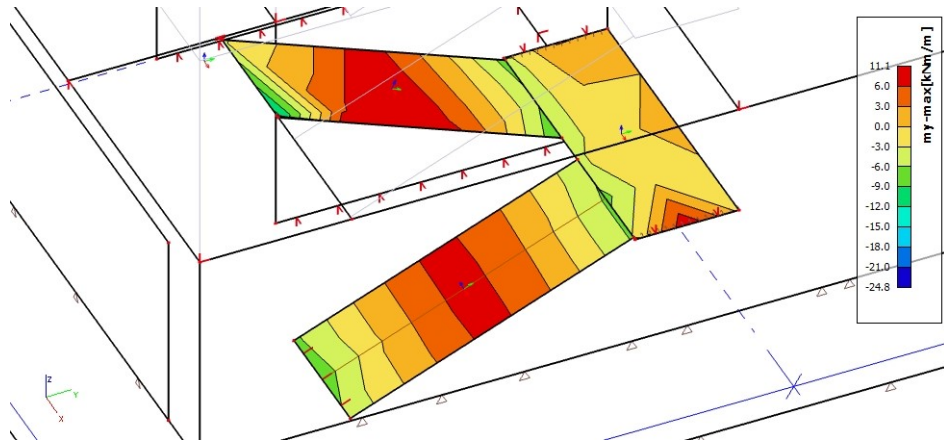


Figure 50-Bending moment of staircase

$$d = h_s - c - \frac{\emptyset}{2} = 100 - 25 - \frac{12}{2} = \mathbf{69 \text{ mm}}$$
 the effective depth.

$$z = 0.9d, z = 0.9 \times 169 = 62.1 \text{ mm}$$

$$\text{The required reinforcement: } A_{S, \text{mid-span}} = \frac{M_{Ed, \text{mid-span}}}{z \cdot f_{yd}} = \frac{11.1}{62.1 \times 435} = 410 \text{ mm}^2$$

$$A_{S, \text{mid-span}} = \mathbf{410 \text{ mm}^2}$$

$$\mathbf{5 \text{ bars with } 12 \text{ } \emptyset \text{ diameter, } A_{S, \text{Prov, mid-span}} = 5 \times \pi \times 6^2 = 566 \text{ mm}^2}$$

$$\text{Position of neutral axis: } x = \frac{A_{S, \text{Prov, mid-span}} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{566 \times 435}{0.8 \times 1000 \times 20} = \mathbf{15.4 \text{ mm}}$$

$$\xi = \frac{15.4}{69} \leq \xi_{\text{bal}} = 0.6, \quad \xi_{\text{bal}} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.22 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_{\text{mid-span}} = d - 0.4 \cdot x_m = 69 - 6.2 = \mathbf{63 \text{ mm.}}$$

$$\text{Bending moment of slab at mid-span} = M_{Rd, \text{mid-span}} = A_{S, \text{Req, mid-span}} \times f_{yd} \times z_{\text{mid-span}} =$$

$$566 \times 435 \times 63 \times 10^{-6} = 24.3 \text{ kN.m.}$$

$$\mathbf{M_{Rd, mid-span} = 15.6 \text{ kN.m} \geq M_{Ed, mid-span} = 11.1 \text{ kN.m. Ok}}$$

8. Wall design

Maximum bending moment from vertical loads

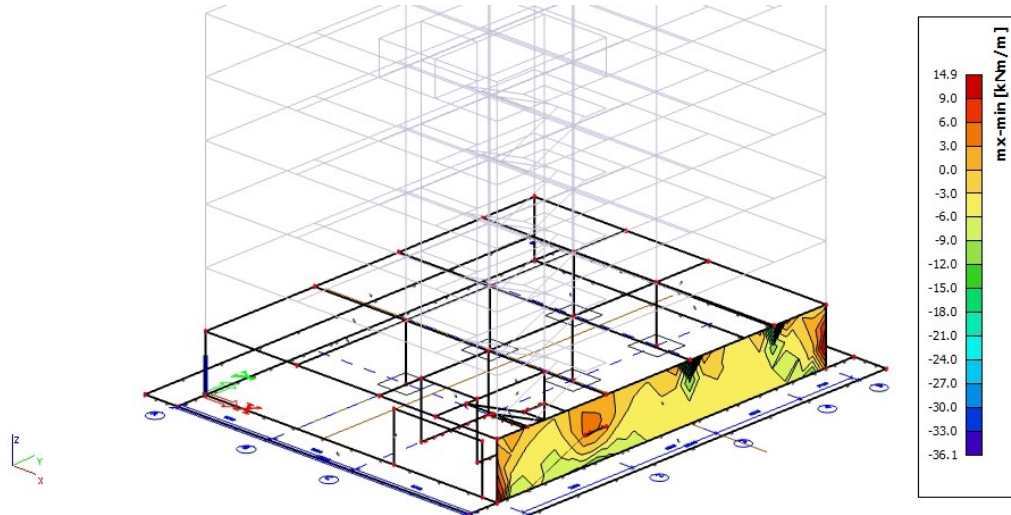


Figure 51 -Bending moment from vertical load

$$M_{Ed,v} = 12 \text{ kN.m.}$$

$$d = t_w - c - \frac{\phi}{2} = 250 - 25 - \frac{12}{2} = \mathbf{219 \text{ mm}}$$
 the effective depth.

$$z = 0.9d, z = 0.9 \times 219 = 197 \text{ mm}$$

$$\text{The required reinforcement: } A_{S,v} = \frac{M_{Ed,v}}{z \cdot f_{yd}} = \frac{12}{219 \times 435} = 125 \text{ mm}^2$$

$$A_S = \mathbf{125 \text{ mm}^2}$$

$$\mathbf{3 \text{ bars with } 8 \text{ } \phi \text{ diameter, } A_{S,Prov,mid-span} = 3 \times \pi \times 4^2 = 151 \text{ mm}^2}$$

$$\text{Position of neutral axis: } x = \frac{A_{S,v} \cdot f_{yd}}{0.8 \cdot b \cdot f_{cd}} = \frac{151 \times 435}{0.8 \times 1000 \times 20} = \mathbf{4.1 \text{ mm}}$$

$$\xi = \frac{4.1}{219} \leq \xi_{bal} = 0.6, \quad \xi_{bal} = \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{yd}}$$

$$\xi = 0.018 \leq 0.6 \text{ ok}$$

$$\text{Lever arm: } z_v = d - 0.4 \cdot x_v = 219 - 1.64 = \mathbf{217 \text{ mm.}}$$

$$\text{Bending moment of wall} = M_{Rd} = A_{S,Req,v} \times f_{yd} \times z_v =$$

$$151 \times 435 \times 217 \times 10^{-6} = 14.2 \text{ kN.m.}$$

$$\mathbf{M_{Rd} = 12 \text{ kN.m} \geq M_{Ed} = 14.2 \text{ kN.m. Ok}}$$

Spacing of rebars $S_v = 250 \text{ mm}$ for vertical reinforcement.

Maximum bending moment from horizontal loads

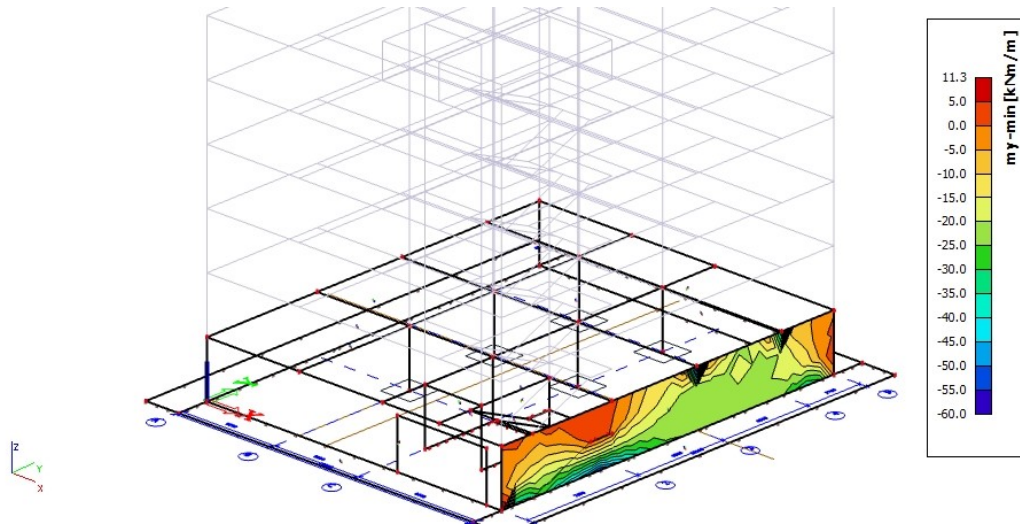


Figure 52 –Bending moment from horizontal load

For the horizontal reinforcement same as in vertical but the spacing of rebars

$S_h = 400$ mm for horizontal reinforcement.

9. Conclusion

When constructing buildings, the contractor is obliged to observe the manufacturer's technological regulations as the static engineering has to follow norms, Eurocodes, etc.

The Eurocodes were followed in the diploma thesis. The static calculation of the entire structure was made by SCIA engineer and drawing were made in AutoCAD.

Design of basic elements of the load-bearing system was carried out. All the elements were designed successfully. Dimensions and reinforcement ratios are within the range typical for buildings. The drawings describing the designed reinforcement were worked out.

The bending moment on the head and foot of the columns was calculated as combinations from the software. Further the check of column in the combination of the maximum bending moment and maximum normal force finally connected by lines **has resulted with the interaction diagram. The slenderness ratio of a column with limiting slenderness were figured out.**

The punching reinforcement was successfully worked out. The effective beam was computed.

10. Bibliography

- Bílý, P. *Seminar of the Concrete structures*, Praha: Ceske Vysoke Ucení Technické, 2014.
- Bílý, P. *Stuffed walls*, Praha: Ceske Vysoke Ucení Technické, 2017.
- Kohoutková, A; Trtik, K.; Vasková, J; Vodicka, J. *Betonové konstrukce I*, Praha: Ceske Vysoke Ucení Technické, 2005.
- Mosley, B; Bungey, J; Hulse, R. *Reinforced concrete design to Eurocode 2*, London: Copyright Licensing Agency, 1988. ISBN 9780230500716
- Procházka, J; Kohoutková, A; Vasková. *Příklady Navrhování Betonových Konstrukcí I*, Praha: Ceske Vysoke Ucení Technické V Praze, 2007.
- Procházka, J; Stemberk, P. *Concrete structures*, Praha: Ceske Vysoke Ucení Technické, 2009.
- Sanda, M. *Betonové Konstrukce II*, Brno: Vysoke Ucení Technické 1984.

Related documents

- EN 1991-1-1 – Loads of structural structures, July 2002
- EN 1992-1-1 Design of reinforced concrete structures buildings, December 2004
- EN 1993-1-1 Design of steel structures of buildings,
- EN 1997-1-1 Base soil under flat foundations
- ISO 690 standard
- ČSN 01 6910 (01 6910) Guidelines for text writing and layout of word processed document.
Prague: Czech office for standards, metrology and testing, June 2014.

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